A TEXTBOOK

ON

STEAM ENGINEERING

INTERNATIONAL CORRESPONDENCE SCHOOLS
SCRANTON, PA

PUMPS
ELEVATORS
STEAM HEATING

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CONTENTS.

PUMPS.

(PART 1.)

GENERAL INTRODUCTION.

DEFINITION.

1. **Pumps** are machines for lifting or conveying fluids, and when not otherwise specified the word is generally understood to mean machines for lifting and conveying water.

WATER.

2. Water is a liquid composed of 1 part of oxygen and 2 parts of hydrogen. The weight of a cubic foot at its maximum density (39.2° F.) is 62.425 pounds; at 32° F., or the freezing point, water weighs 62.4 pounds per cubic foot, and at 212° F., or the boiling point, water weighs 59.7 pounds per cubic foot. Obviously pumping machinery can only handle water between the limits of the freezing and boiling points. Water is almost non-compressible; its compressibility is about .0000014 of its volume under a pressure of 15 pounds per square inch, and it decreases with an increase of temperature; for practical purposes it may be considered as incompressible.

HOW WATER FLOWS INTO A PUMP.

3. **Pumps** are frequently so located that the water must into the pump cylinder by atmospheric pressure on the ace of the water external to the suction pipe; that is, by

the action of the pump a vacuum of more or less perfection is produced in the pump chamber. If the end of the suction pipe, which is the pipe connecting the pump chamber with the water, is submerged, the excess of pressure on the surface of the water outside of the suction pipe will cause the water to rise in the suction pipe until the pressure due to the weight of the column equals the pressure of the atmosphere.

THEORETICAL LIFT.

4. The pressure of the atmosphere is constantly changing. For practical purposes the pressure at sea level is taken as 30 inches of mercury, or 14.7 pounds pressure per square inch. Since a pressure of 1 pound per square inch is equal to that exerted by a column of water 2.309 feet high, the theoretical height that water can be raised by a perfect vacuum at sea level will be $14.7 \times 2.309 = 33.94$ feet. Since the atmospheric pressure becomes less as the altitude increases, it follows that the greater the altitude, the less the theoretical and practical lift by atmospheric pressure will be. To find the theoretical height in feet to which water can be lifted at any altitude, multiply the barometric reading in inches by 1.133.

5. For water holding foreign substances in suspension, or for other liquids, the theoretical lift can be found by dividing the theoretical height to which water can be lifted at the existing atmospheric pressure, as shown by the barometer, by the specific gravity of the liquid.

ACTUAL LIFT.

[illegible] perfect vacuum cannot be obtained on account [illegible] imperfections, air contained in the water, and [illegible] the water itself, the actual height to which it [illegible] is only about .82 of the theoretical height, [illegible] good only for pure water.

[illegible] case of pumps located at the bottom of deep [illegible] barometer will plainly show a greater pressure on

the bottom than at the surface, and hence a greater suction lift is possible at the bottom.

PUMPING HOT WATER.

8. Pumping hot water is a difficult problem and has positive limitations in the direction of lift and temperature. Whenever possible, the pump should be so arranged that the hot water will flow to it. The following table shows the theoretical possibilities at 30 inches barometric pressure:

INFLUENCE OF TEMPERATURE ON SUCTION LIFT.

Temperature. Degrees Fahrenheit.	Suction Lift. Feet.
100	28.0
150	21.0
170	17.0
190	10.0
210	1.5

In actual practice it is not possible to lift water at all whose temperature exceeds 180°. The reason hot water cannot be lifted is on account of the increased pressure of the vapor at the higher temperatures. Pumps required to handle hot water should be provided with suitable valves of vulcanized rubber for the lower temperatures and metal for the higher temperatures. Soft rubber valves are unsuited for handling hot water.

LIMIT OF HEIGHT TO FORCING.

9. Having considered the limit of lift by suction, the limit of height to which water or any other liquid can be forced will be discussed now. This height is *not* affected by

the atmospheric pressure and is only limited by the power available for forcing the liquid and the strength of the pump and the pipe connections.

GENERAL CONSIDERATIONS.

10. Before proceeding to give an account of some of the best and most modern types of pumps, let us consider for a moment what is required to be done in order that large volumes of water may be raised in the best possible manner and with the best possible economy. Among the first things that a practical engineer should know and among the last things he should forget is that in handling water within pipes he has a fluid which, while it is flexible to the greatest extent and is susceptible to the influence of power or force of greater or less intensity, and while it may be drawn from below and raised to a height above, and while it bends itself to the will of the engineer, will still refuse to do some things and which all the complicated appliances of the engineer have as yet failed to compel it to do. When enclosed within chambers and pipes to an extent that fills them, it will not permit the introduction of any more without bursting them. When enclosed within long lines of pipes, it will *not* suddenly start into motion or when in motion suddenly come to rest without shocks or strains more or less disastrous.

HISTORICAL.

11. Almost the first application of steam was to pumps used for raising water out of mines, and as these pumps had previously been entirely operated by horses, a basis of comparison was established by rating the power of the steam engine by the number of horses it displaced at these mine pumps. To enumerate even briefly the various machines for pumping water that have been developed in the past, many of which are famous, would be quite impossible for lack of space, and a description of their peculiar and prominent characteristics would be equally so, especially as they are only of historic interest. Conditions have so changed

as regards steam pressure, speed, and problems of manufacture and competition that out of the great mass of pump designs, some of which were excellent in many points, have been developed standard forms of pumps particularly adapted to each and every service.

CLASSIFICATION.

12. Pumps may be classified in a number of different ways, as according to their principle of operation, their general form, the power used to drive them, the methods of applying the power, the special class of work to which they are applied, etc. There being no universally accepted classification, no attempt will be made here to classify pumps, but the different forms of pumps described will be given the name by which they are most generally known.

STEAM PUMPS.

DEFINITION AND DIVISION.

13. Steam pumps are pumps in which the moving force is steam, which is applied to the movement of water without the intervention of belting or gear-wheels. Steam pumps are divided into two general classes known, respectively, as *direct-acting* and *flywheel-pattern* pumps.

DIRECT-ACTING STEAM PUMPS.

INTRODUCTION.

14. General Description.—The type of pump by far the most numerous is the **direct-acting pump,** by which is meant a steam-driven pump in which there are no revolving parts, such as shafts, cranks, and flywheels, or pumps in which the pressure of the steam in the steam cylinder is

transferred to the piston or plunger in the pump in a direct line and through the use of a continuous rod or connection. In pumps of this construction the moving parts have no weight greater than that required to produce sufficient strength in such parts for the work they are expected to perform; as there is, consequently, no opportunity to store up power in one part of the stroke to be given out at another, it is impossible to cut off steam in the cylinder during any part of the stroke. The uniform and steady action of the direct-acting steam pump is dependent alone on the use of a steady, uniform pressure of steam throughout the entire stroke of the piston against a steady, uniform resistance of water pressure in the pump, the difference between the power exerted in the steam cylinders over the resistance in the pump governing the rate of speed at which the piston or plunger of the pump will move. The length of the stroke of the steam piston within these pumps is limited and controlled by the admission, release, and compression of the steam in the cylinder.

15. Development.—The direct-acting steam pump was invented by Henry R. Worthington in the year 1840 and was patented in 1841. A few years later Mr. Worthington developed and brought out what is now known as the *duplex* direct-acting steam pump. The objection to the single direct-acting pump was the fact that the action of the pump plunger or piston was an intermittent one; that is, the column of water was started into motion at the beginning of each stroke and came to a stand at the end of each stroke, thus not only making the flow of the water irregular, but also subjecting the pump and the connecting pipes and their joints to severe and often serious strains.

16. Duplex Pumps.—In the main, the construction of the steam and water ends of the duplex pump differs but slightly from that of the single direct-acting pump, but the mechanism that operates the steam valves is different and the effect on the water column is very different. The principle upon which the duplex pump operates is this: Two

pumps of similar construction are placed side by side; a lever attached to the piston rod of each pump connects to the slide valve of the opposite steam cylinder, and thus the movement of each steam piston, instead of operating its own steam valve, as in the single pump, operates the slide valve of the opposite cylinder. The effect of this arrangement is that as the piston or plunger of one pump arrives at or near the end of its stroke, the plunger or piston of the other begins its movement, thus alternately taking up the load of the water column and producing a regular, steady, onward flow of water without the unusual strains induced by such a column of water when suddenly arrested or started in motion.

17. Advantages of Direct-Acting Pumps.—The direct-acting machine is the simplest form of pump yet devised; its action most nearly harmonizes with the laws controlling the action of water, and in event of a conflict, the direct-acting pump will yield to the superior force of the water without serious resistance. The direct-acting pump being not only the simplest but most universally used type of pump it will be taken up first.

18. Disadvantages of Direct-Acting Pumps.—To obtain perfection of steam pumps it is necessary to use the steam so that by cutting it off within the steam cylinders and by subsequent expansion in the same or other cylinders, its expansive force will be developed to the highest limit and to the most economical extent. When that is done we have accomplished all that with our present knowledge of the steam engine can be done in the steam cylinders. It is in this respect, however, that the direct-acting steam pump of the ordinary type is anything but economical, its design requiring the carrying of the full steam pressure throughout the whole stroke. This drawback prohibits its use in places where a high economy in the use of steam is imperative. By the use of a so-called **high-duty attachment,** however, the ordinary direct-acting pump can be and is converted into a machine using steam expansively; a fair degree of economy is also obtained by compounding the steam end.

VALVE MOTIONS.

19. The Knowles Valve Motion.—Fig. 1 shows the steam end of the Knowles steam pump with the arrangement of the valve gear

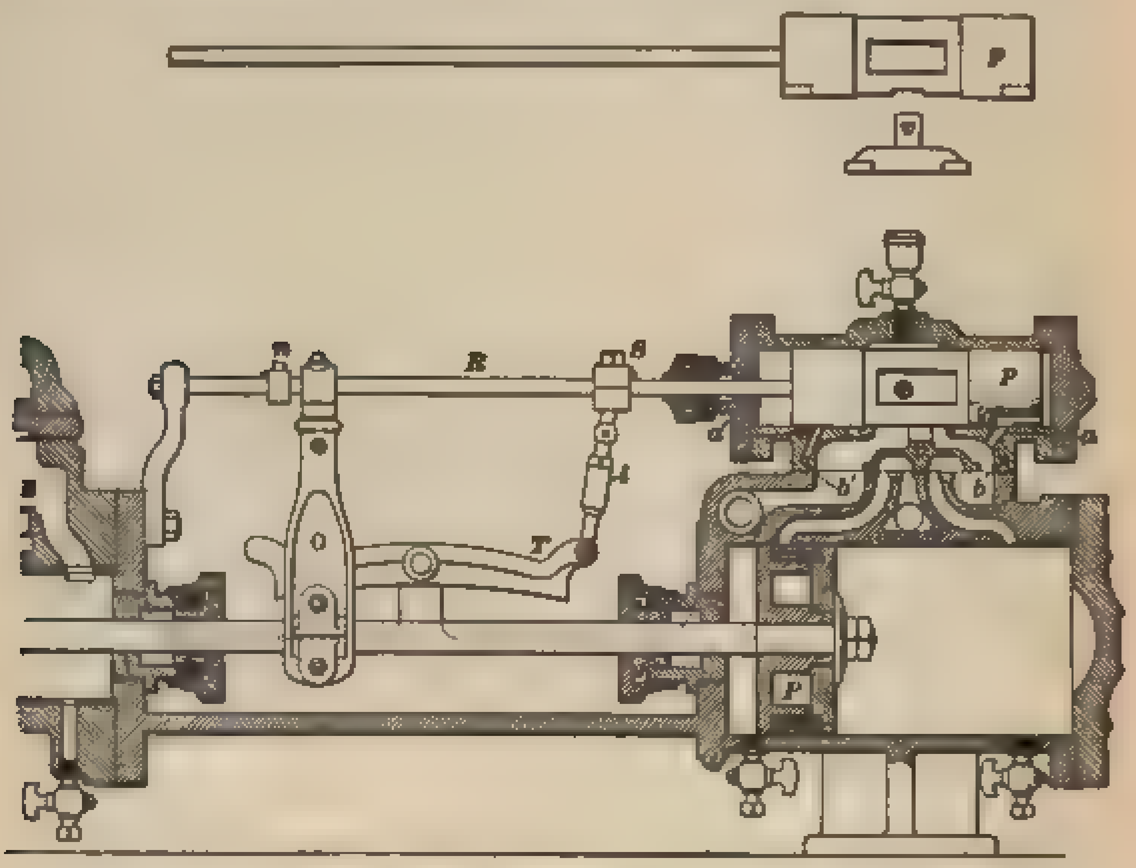


FIG. 1

An auxiliary piston *p* works in the steam chest and drives the main valve *v*. This auxiliary, or **chest piston,** as it is called, is driven backwards and forwards by the pressure of the steam, carrying with it the main valve, which in turn gives steam to the steam piston *P* and operates the pump The main valve *v* is a plain slide valve of the B form working on a flat seat. The chest piston has a rod *R* to which is clamped an arm *S*, the latter being connected to the rocker bar *T* by a link *l* The main piston rod carries an arm *O*, which is provided with a stud, or bolt, on which there is a friction roller. This roller moves back and forth under the curved rocker bar with the motion of the main piston rod and lifts the ends of the bar, thus giving the chest piston a slight rotary motion just at the end of the stroke of the main piston.

Each end of the chest piston is provided with a port *o*, shown in the right-hand end by the partial section, and the solid part of the steam chest has four ports *a*, *b* and *a'*, *b'*, which open into the space in which the chest piston moves. The ports *a* and *a'* connect with the live steam space in the steam chest and serve as steam ports, while *b* and *b'* connect with the exhaust. In the position shown in the figure, the main piston has just reached that point of its stroke where the roller has acted on the rocker bar to rotate the chest piston. This has brought the port *o* (in the right-hand end of the chest piston) into communication with the live steam, admitting the latter to the space at the right of the chest piston. This steam drives the chest piston to the left and it carries the main valve *v* with it, thus exhausting the steam from the right of the main piston and admitting live steam to the left. When the main piston, under the action of this steam, approaches the right end of the cylinder, the roller lifts the right end of the rocker bar, thus rotating the chest piston so as to bring the port *o* in connection with the exhaust port *b* and the port in the opposite end of the chest piston in connection with the steam port *a'*. This drives the chest piston and main valve to the right, allows the steam at the left of the main piston to exhaust, and admits live steam to the right of the main piston again. The chest piston, as it approaches either end of its chamber, covers the exhaust port at that end, thus confining enough of the exhaust steam to form a **cushion** to prevent it from striking the end of the steam chest. The main piston also covers the exhaust port before reaching the end of its stroke, as shown in the figure, so that it is cushioned by the exhaust and prevented from striking the cylinder head. Special passages are provided for admitting the steam required to move the piston far enough to uncover the main ports on the return stroke. The arm *O* carries a collar that slides over the chest piston rod, and in case the steam pressure is not sufficient to move the chest piston, this collar will strike collars, as *n*, and thus move the valve. (One of these collars is just behind the arm *S*.)

20. The Cameron Valve Motion.—In the Cameron pump shown in Fig. 2, which possesses the advantage of

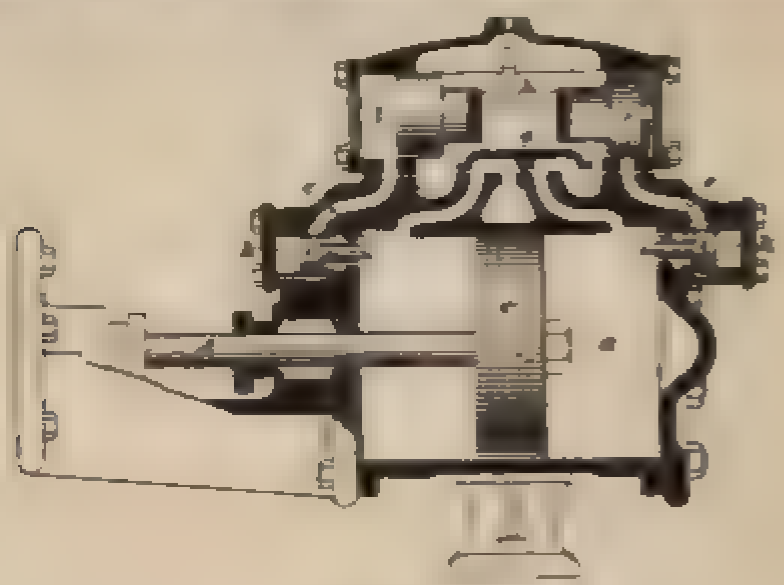


FIG. 2

having no outside gearing, *a* is the steam cylinder, *c* the piston, *d* the piston rod, *f* the steam chest, *g* the chest piston, the right-hand end of which is shown in section, *h* the main slide valve, *k* the starting bar, connected with a handle on the outside, *l*, *l* the reversing valves, *m*, *m* the bonnets over the reversing-valve chambers, and *n*, *n* are exhaust ports leading from the ends of the steam chest direct to the main exhaust and are closed by the reversing valves *l*, *l*.

The action of this valve motion is as follows: The spaces at the ends of the chest piston *g* communicate with the live-steam space by means of small holes, one of which is shown in the right-hand section at [illegible]. By means of these holes, [illegible] the ports [illegible] from them are kept [illegible] as long as the ports are covered by the valves *l*, *l*. In the position shown in the figure, the [illegible] to the right of the piston [illegible] is in [illegible] with the live-steam space in the steam [illegible] moving to the left. When *c* strikes [illegible] into the left and [illegible] allowing the steam at the [illegible] the [illegible] the main

valve *g* to the left, thus reversing the action of the steam on *c*, which immediately begins to move back towards the right. Live steam is always acting on the piston *i*, so that as soon as *c* moves to the right, this steam pushes *i* back and covers the left port *e* again, after which live steam fills the port and the space connecting with it through the small hole in the end of *f*. When the piston *c* strikes the stem of the right hand valve *i*, the main valve is again shifted to the right and *c* is started on its stroke to the left. Exhaust steam is confined in the ends of the cylinder to prevent the piston from striking the heads, in the same manner as in the Knowles steam pump.

21. The Gordon Steam Pump.—If the load is suddenly thrown off from the ordinary direct-acting steam pump

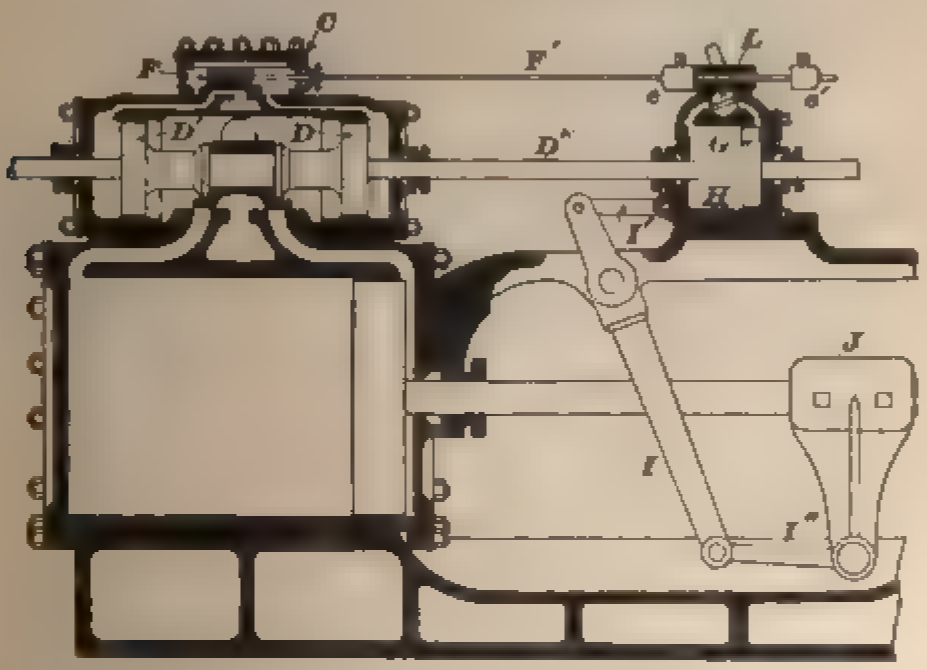


FIG. 3

through any cause, as, for example, the bursting of the discharge pipe or the opening of a valve, so as to permit the water to discharge freely under low pressure, the steam is liable to drive the piston to the end of its stroke with so much force as to cause serious shocks or even to break some part of the pump. In order to overcome this danger the *Gordon* steam pump is provided with the arrangement shown in Fig. 3, which is called an **isochronal valve gear.**

H S I - 2

In this gear the main valve is operated by a double chest piston *D D'*, which is actuated by steam controlled by an auxiliary slide valve *F* in the small steam chest *C*. *F* is provided with a valve stem *F'*, to which two collars *e*, *e'* are fastened with setscrews. A slide *H*, which receives its motion from the main piston rod by means of links *I'* and *I''*, the lever *I*, and the crosshead *J*, strikes the collars *e*, *e'* near the ends of the main piston stroke, thus moving the auxiliary valve *F* and admitting steam to the chest piston *D D'*, which in its turn operates the main steam valve and reverses the motion of the main piston. In order to prevent the pump from running away when the load is thrown off suddenly, the slide *H* carries a cylinder in which works a piston *G* fastened to the rod *D''* of the chest piston *D D'*. This cylinder, called the **cataract cylinder**, has a cock *L* that controls a passage joining its two ends, and by means of this cock the passage may be more or less closed, as desired.

The action is as follows: Assume the cataract cylinder to be empty; the piston *G* will then meet with no resistance and the machine will work as usual. At the end of the stroke the slide *H* will strike one of the stops *e* or *e'*, thus shifting the auxiliary valve *F* and admitting steam to the piston valve *D D'*, which will move freely through its stroke and thus admit steam to the main piston for the return stroke. Now, if something happens to the water discharge, as, for example, the breaking of a pipe, the load will be removed from the pump and the main piston will be driven suddenly to the end of its stroke and thus be in danger of striking the head with enough force to break it. The object of the cataract cylinder is to overcome this danger. It is filled with liquid, which must be forced from one end to the other by the motion of the piston *G*. By partly closing the cock *L* a resistance is opposed to the passage of the liquid, and the motion of the piston *G* through its cylinder may be made as slow as desired; consequently, when the main piston moves too rapidly, the motion of the slide *H* will be transmitted to the piston *G*, which will shift the main valve

so as to shut off the supply of steam to the main piston and thus prevent the pump from running too fast.

22. The Marsh Steam Pump.—The **Marsh valve motion** shown in Fig. 4 operates without any connection to

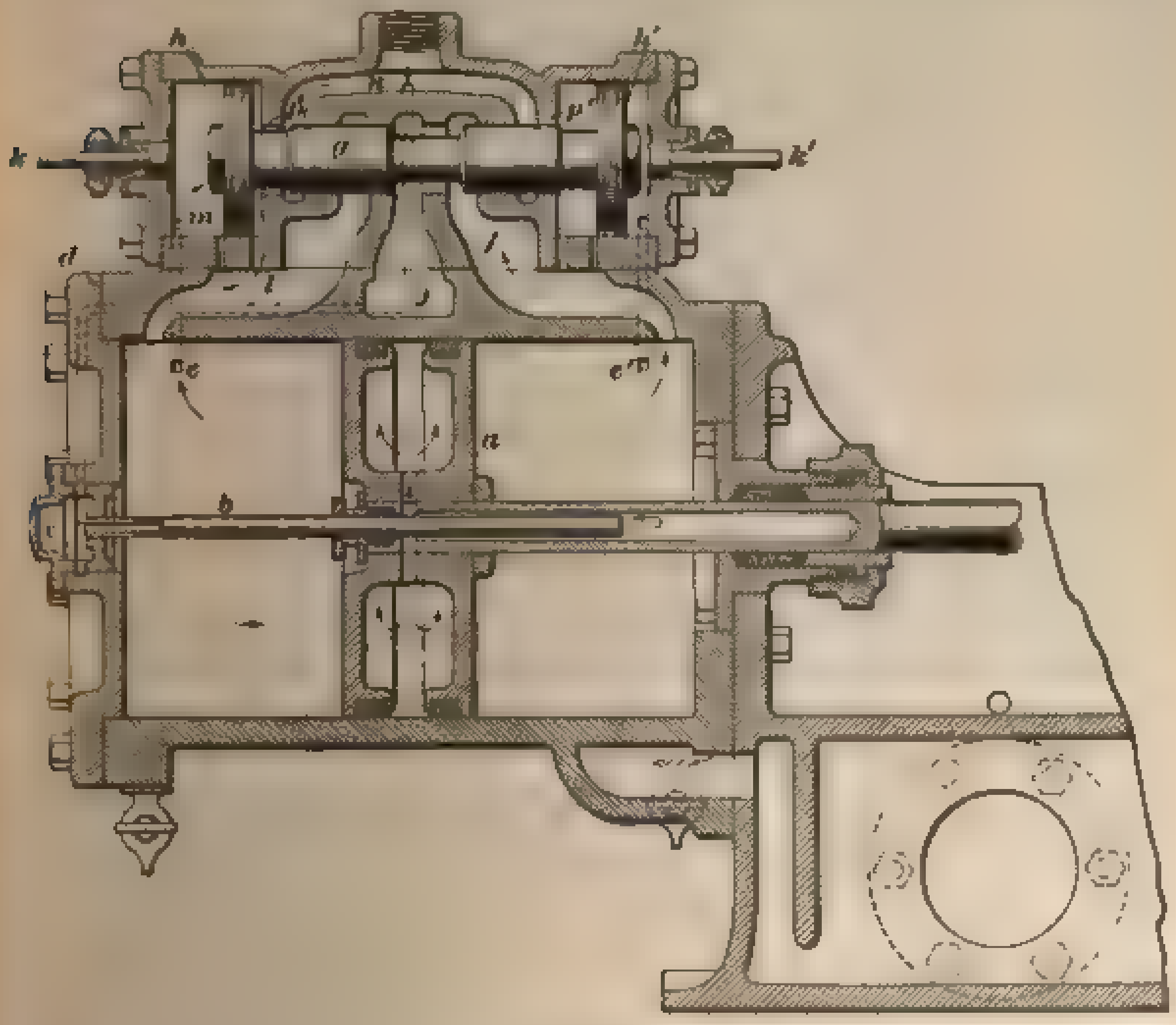


FIG. 4.

the piston or rod. The steam piston *a* is made in two parts, each section being provided with a packing ring so arranged as to provide an annular space between the two piston halves. Steam at boiler pressure is admitted within the pistons by means of the tube *b*, which is rigidly secured to and is in communication with the chamber *c*. A stuffingbox in the piston through which it plays prevents leakage into the main steam cylinder. A small port *d*, shown by dotted lines, supplies steam to the chamber *c*. When the piston is moving to the right, steam is entering from the space *n* through the annular opening between the reduced neck of the valve *g* and

bore of the left chest wall *p*. It is thus projected against the inside surface of the valve head *h* before escaping through the port and passing into the cylinder. Both the pressure and the impulse due to the velocity of the entering steam act on the valve head *h* and tend to force it to the left, thus tending to close the annular opening in the chest wall *p*. The steam flowing through the annular opening and port *l* into the cylinder also flows through the small ports *m* and *e* to the left of the valve head *h*. The steam entering through these ports is wiredrawn, so that its pressure is reduced, but it has a greater area of the valve head *h* exposed to its pressure than the steam on the right of *h*. Hence, the valve *g* moves to a position where the total forces acting on the two sides of *h* are equal and then remains stationary. The steam entering through the annular opening in the chest wall *p* is also wiredrawn, so that the pressure on the left of the piston *a* is below the full boiler pressure existing in *n*.

While the piston *a* is moving to the right, the steam on the right is exhausting through the port *f* into the exhaust port *j*. The exhaust is first closed by the piston running over the port *f*; as soon as this port is covered, the port *e'* leading to the right of the valve head *h'* communicates with the space within the piston containing steam at boiler pressure, and this live steam rushes into the space to the right of the valve head *h'*. Since the steam pressure on the left of *h* is less than the pressure on the right of *h'*, the valve moves to the left, and by doing so closes the left steam inlet, opens the left exhaust, and also opens the right steam inlet in the chest wall *p'*. The live steam admitted to the right of the piston *a* first brings it to rest and then reverses its motion. The tappets *k* and *k'* are used for moving the valve by hand in case the valve is stuck.

DUPLEX PUMPS.

23. Types.—Duplex pumps, like single direct-acting pumps, are made either as piston pumps or as plunger pumps. When made as plunger pumps, they may have either

inside-packed, center-packed, or outside-packed plungers. Piston pumps are preferred for moderate pressures, but for pumping against very high pressures the plunger pump is generally used.

24. Slide-Valve Worthington Duplex Pump.—Fig. 5 is a perspective view of a piston pattern Worthington

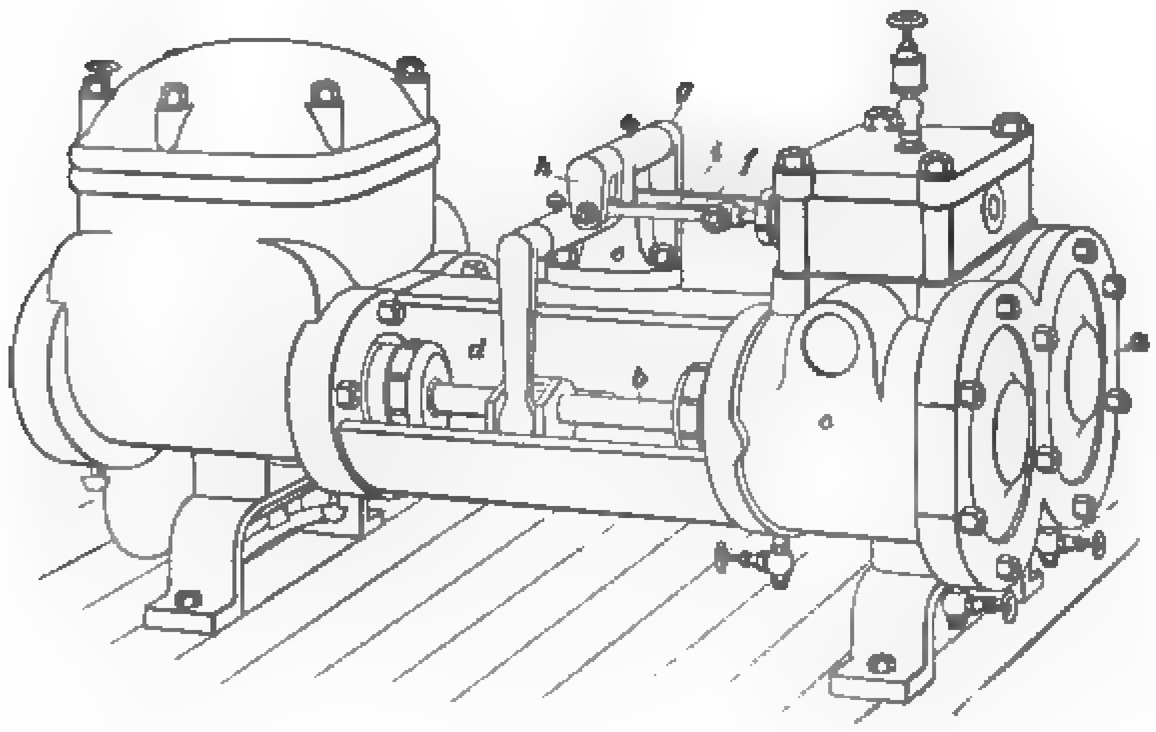


FIG. 5.

duplex pump, which shows the general arrangement of the valve motion. The two pistons always move in opposite directions, and the steam valve for the cylinder *a* is worked from the crosshead of the piston rod *b* of the cylinder *c* through the lever *d*. This lever passes through the standard *e*; it is keyed to a shaft that carries a crank in line with it at the other side of the standard, and to this crank the valve rod *f* is attached. The valve rod in turn is hinged to the valve stem. The valve of the cylinder *c* is operated from the piston rod of the cylinder *a* through the lever *g*, the crank *h*, and the valve rod *i*.

25. Fig. 6 is a sectional view through the center of the cylinder *a*, Fig. 5, and shows the construction of the steam end peculiar to the Worthington pump. Incidentally it also

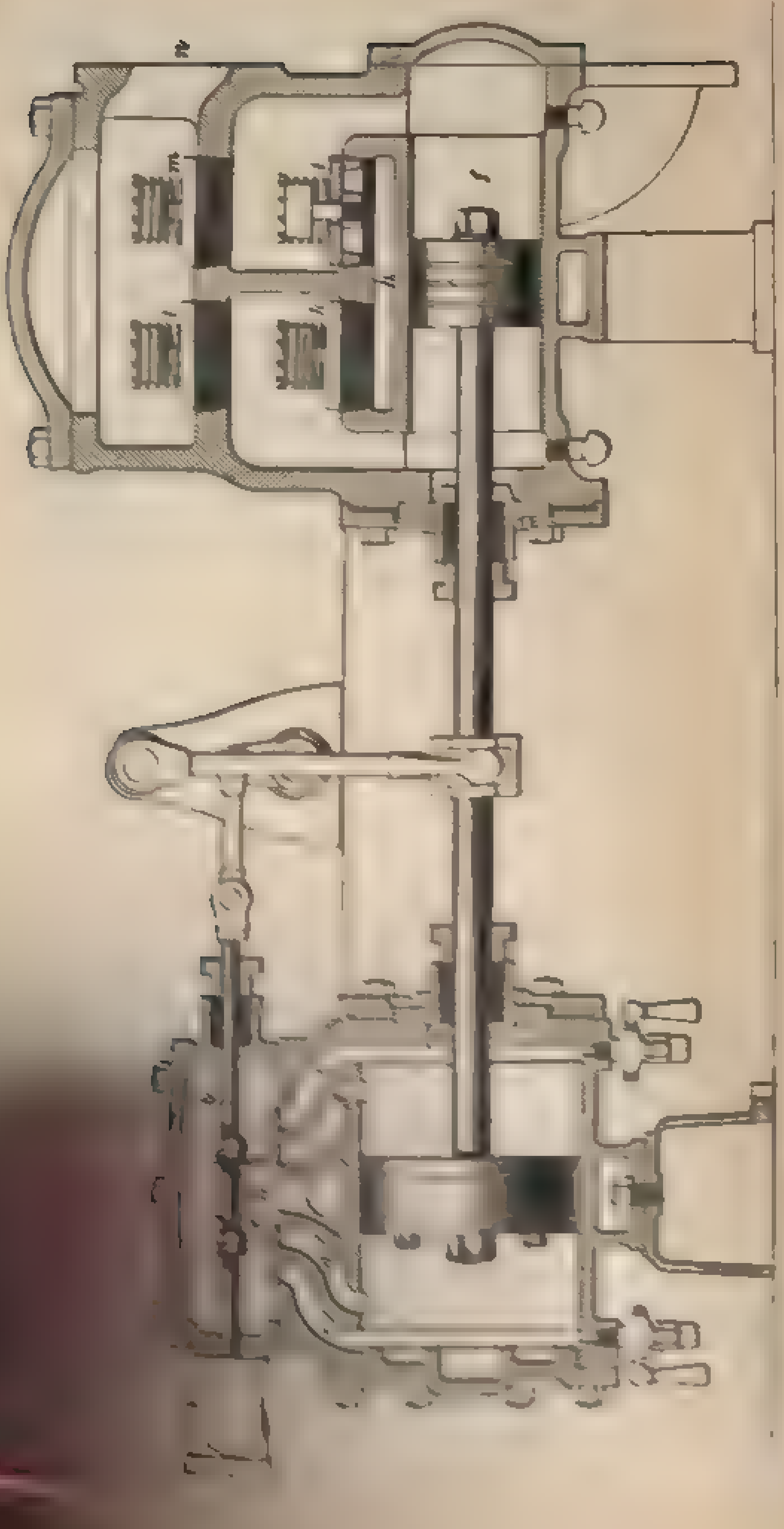
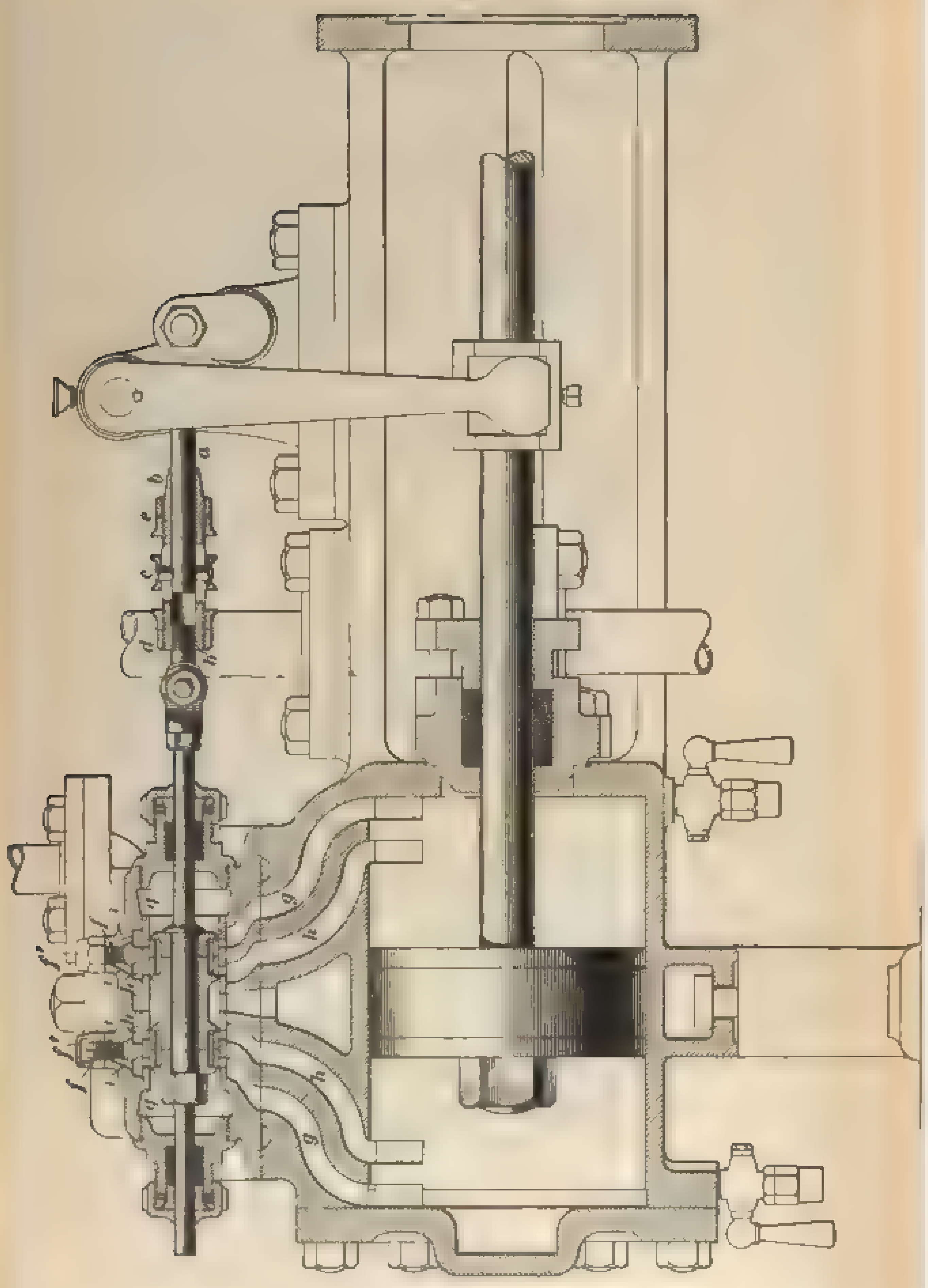


FIG. 6

shows one form of construction of the water end of a double-acting pump. The steam valve *a* is a simple **D** slide valve operated by the valve stem *b*. There are two ports communicating with each end of the steam cylinder, of which the outer ones *c*, *c* are the steam ports and the inner ones *d*, *d* the exhaust ports. By this arrangement, when the piston approaches the end of its stroke, it covers the exhaust port and thus confines some steam in the cylinder that serves as a cushion. The valve has neither inside nor outside lap, and hence steam cannot be used expansively. The steam valve is carried along by coming in contact with check-nuts on the valve stem *b*, so placed that there is some lost motion between them and the valve. By this means the steam piston is caused to be at rest for a short time at the end of the stroke, which dwell allows the water valves to seat quietly.

26. In the water end the water is displaced by a piston *e* provided with suitable packing and working in the cylinder *f*. The water flows to the pump through the suction pipe connected to the lower nozzle and through the passage *h* to the suction valves *i* and *k*. The water is discharged through the discharge valves *l* and *m* into the discharge pipe connected at *n*. The operation is as follows: the piston *e* moving to the left, the suction valve *i* lifts and the discharge valve *m* remains closed, and water flows into the right-hand end of the cylinder. At the same time the water at the left end of the cylinder flows through the discharge valve *l*, which is lifted by the flow of water, while the suction valve *k* is kept closed. When the piston moves to the right, the suction valve *k* opens and the discharge valve *l* closes; at the same time the suction valve *i* closes and the discharge valve *m* opens. The pump is thus seen to discharge and take water during both strokes of the piston, and hence is double-acting.

27. Piston-Valve Worthington Duplex Pump.—Fig. 7 shows the steam end of a Worthington duplex pump



in which piston valves are used instead of slide valves. The valves are operated in practically the same manner as those of the pump shown in Fig. 5, but the lost motion instead of being between the valve and stem is obtained by a special construction of the valve rod *a*. This rod is divided into two parts. The part attached to the valve stem carries a slotted yoke *b*; the part attached to the crank is free to slide within the yoke and carries a collar *c* pinned to it. The collar *c* alternately strikes against the check-nuts *d* and *e* on the yoke *b* and then carries the valve with it. The lost motion is quite large, as the valve needs to be moved but a slight amount.

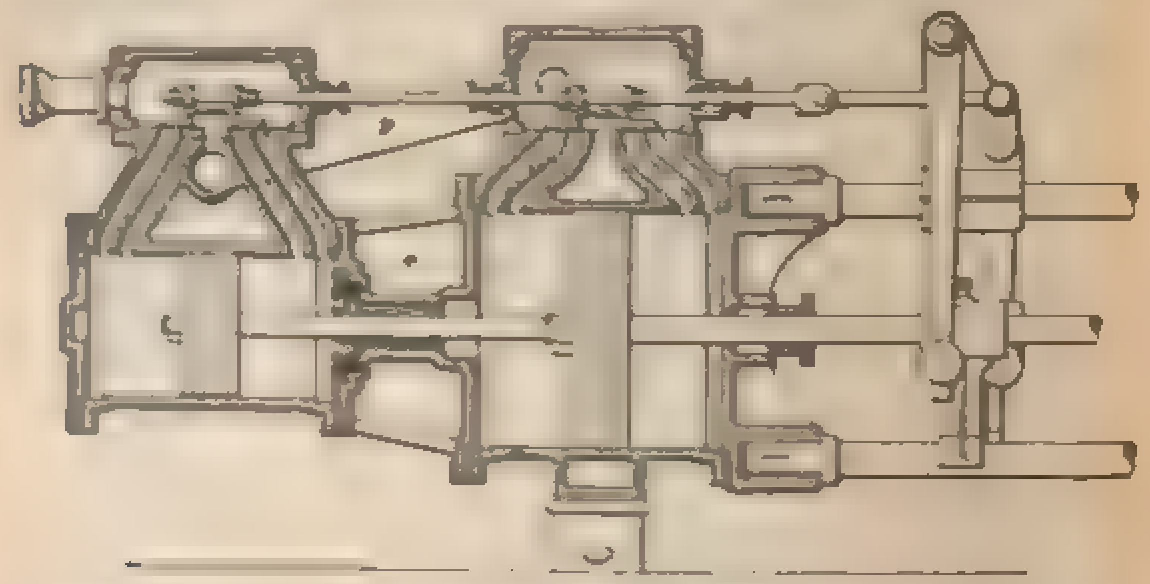
28. The length of stroke is adjusted by the use of the so-called **dash relief valves** *f*, *f*. These valves control passages *i*, *i* connecting the steam ports *g*, *g* and exhaust ports *h*, *h*, and are set by trial to the correct position and then locked with the cap nuts *f'*, *f'*. The action is as follows: When the piston on its exhaust stroke covers the port *h*, no further exhaust can take place, and the steam will be compressed between the piston and the cylinder head. The location of the ports *h*, *h* is so chosen that the compression will stop the piston just short of the cylinder head at the highest speed at which the pump can operate. It is evident that when the pump is working at slow speed, the compression being the same as at high speed but the momentum of the moving parts being less, the piston will stop earlier than at high speed; i. e., the stroke is shortened. The dash relief valves prevent this shortening by providing an escape for the exhaust steam after the exhaust ports *h*, *h* are closed. It is thus seen that by them the amount of compression is regulated to suit the speed of the pump and the length of stroke is thus kept constant.

Dash relief valves are applied to pistons over 14 inches, as a general rule, and are used with slide-valve pumps as well as with piston-valve pumps. In either case they simply control a passage by which the exhaust port and steam port communicate.

MULTIPLE-EXPANSION DIRECT-ACTING STEAM PUMPS.

29. Purpose.—In the simple direct-acting steam pumps, no use can be made of the expansive force of the steam. They are, therefore, very extravagant in the use of steam, and in order to overcome this waste to a greater or less extent, many of the larger pumps are made with either compound or triple-expansion engines.

30. Compound Pump.—Fig. [illegible] shows a common method of arranging the cylinders for a **compound duplex** pumping



engine. The engine for each pump is made with two cylinders [illegible] being [illegible] The high-pressure cylinder [illegible] the low-pressure [illegible] which forms one [illegible] *receiver* [illegible] passes [illegible] the space [illegible] the body [illegible] high-pressure [illegible] low-pressure [illegible] the [illegible] times [illegible], neglecting

the resistance to the flow of steam through the ports and the pipe *p*.

Since the volume of steam admitted during each stroke is equal to the volume of the high-pressure cylinder, and this steam, when exhausted, just fills the low-pressure cylinder, it is evident that the number of expansions is equal to the ratio of the volume of the low-pressure cylinder to that of the high-pressure cylinder. Also, since the length of stroke is the same for both cylinders, the number of expansions is equal to the ratio of the areas of the low- and the high-pressure piston. The usual number of expansions for small and medium sizes ranges from two to three. For large sizes four expansions are sometimes used.

31. Compound pumps are also made in which the cylinder arrangement is just the reverse from that shown in Fig. 8. In some of these compound pumps the high-pressure cylinder has no separate steam and exhaust ports; the compression and adjustment of length of stroke then takes place in the low-pressure cylinder.

32. Triple-Expansion Pump. — In triple-expansion pumping engines of the direct-acting class, the arrangement shown in Fig. 9 is sometimes adopted for the steam end. This design makes all the pistons accessible and at the same time avoids the use of a stuffingbox between the high-pressure cylinder *A* and intermediate cylinder *B*. The low-pressure piston and intermediate piston are connected by the piston rod *c*, and the low-pressure piston is connected to the high-pressure piston rod by the side rods *e*, *e* and the yoke *f*. The piston rod *c* is nicely finished and ground and works through a cast-iron bushing *g*, which is a nice fit. This bushing can move sidewise slightly so as to accommodate any want of alinement between the two cylinders. At the same time it prevents leakage of steam from the intermediate cylinder *B* to the low-pressure cylinder *C*. The low-pressure and high-pressure stuffingboxes are quite accessible. Access to the different pistons is had by removing the covers *h*, *i*, and *k*.

33. Fig. 10 is a vertical longitudinal section of the pump whose piston rod and cylinder arrangement is shown in Fig. 9 and shows the steam distribution in this form of pump. In the illustration, *A* is the high-pressure cylinder, *B* is the intermediate-pressure cylinder; *C* is the low-pressure cylinder; *d* is the high-pressure distributing valve, and *e*, *e* are the high-pressure cut-off valves. Steam enters through the center of the valve *d* and passes through the port *f* and through the cut-off port *g* into the high-pressure cylinder by way of the port *h*. The cut-off is effected by turning the rotary valves *e*, *e*. Exhaust from the high-pressure cylinder takes place through the ports *j*, *j* and thence into the high-pressure exhaust *k*, which leads to the inside of the intermediate steam valve *l*. The valve *l* is a rotary valve designed to distribute the steam exactly in the same manner as a common D slide valve. The intermediate- and low-pressure cylinders are not provided with cut-off valves. The exhaust steam from the intermediate cylinder passes out through the port *m* into the

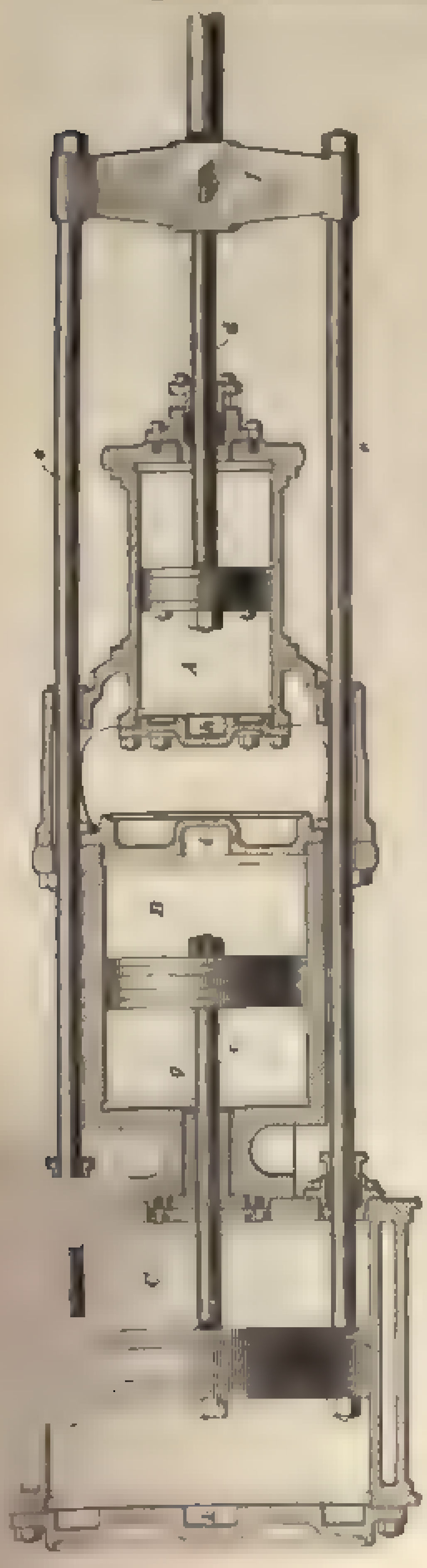


Fig. 9

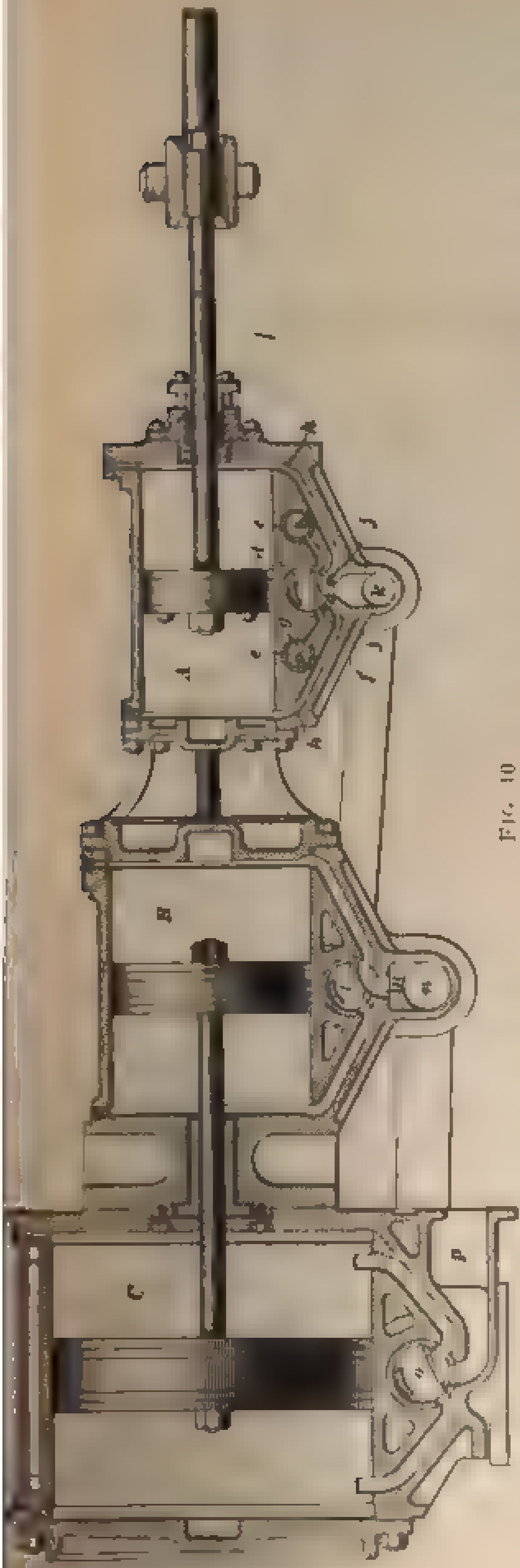


Fig. 10

exhaust pipe *n*, and thence to the center of the low-pressure distributing valve *o*. From the low-pressure cylinder the steam is exhausted into the exhaust chest *p* and thence into the condenser or atmosphere. Dash relief valves, not shown in the illustration, are provided on the low-pressure cylinders only. The distributing valves are worked as usual from the pump on the opposite side, while the cut-off valves are worked from the pump on which they are placed.

34. Cross Exhaust. Compound duplex direct-acting pumps are occasionally provided with a so-called **cross-exhaust** connection, the purpose of which is the keeping of a more uniform pressure in the steam chests of the low-pressure cylinders than obtains otherwise. As shown in Fig. 11, it is simply a pipe *a* of ample size, which is provided with a valve *b* and connects the steam chests of the low pressure

cylinders. The exhaust from the high-pressure cylinders c, c flows through the exhaust pipes d, d into the low-pressure steam chests e, e, but as the steam pressure there drops towards the end of the stroke, there is a diminishing of the

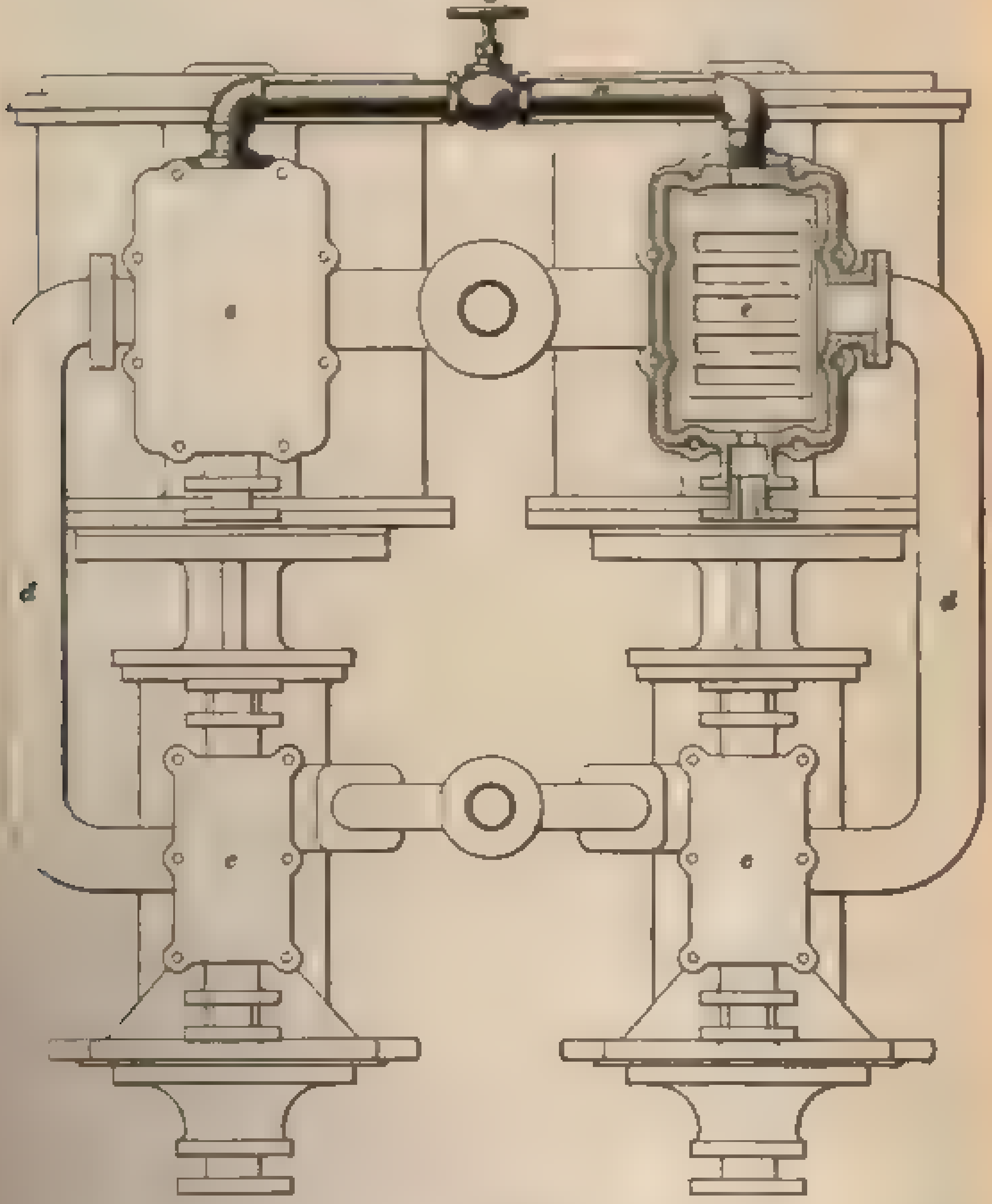


FIG. 11

impelling force on the steam pistons of the low-pressure cylinders that tends to shorten the stroke. With the valve b open, the exhaust from the high-pressure cylinder of one pump can pass to the low-pressure steam chest of the other

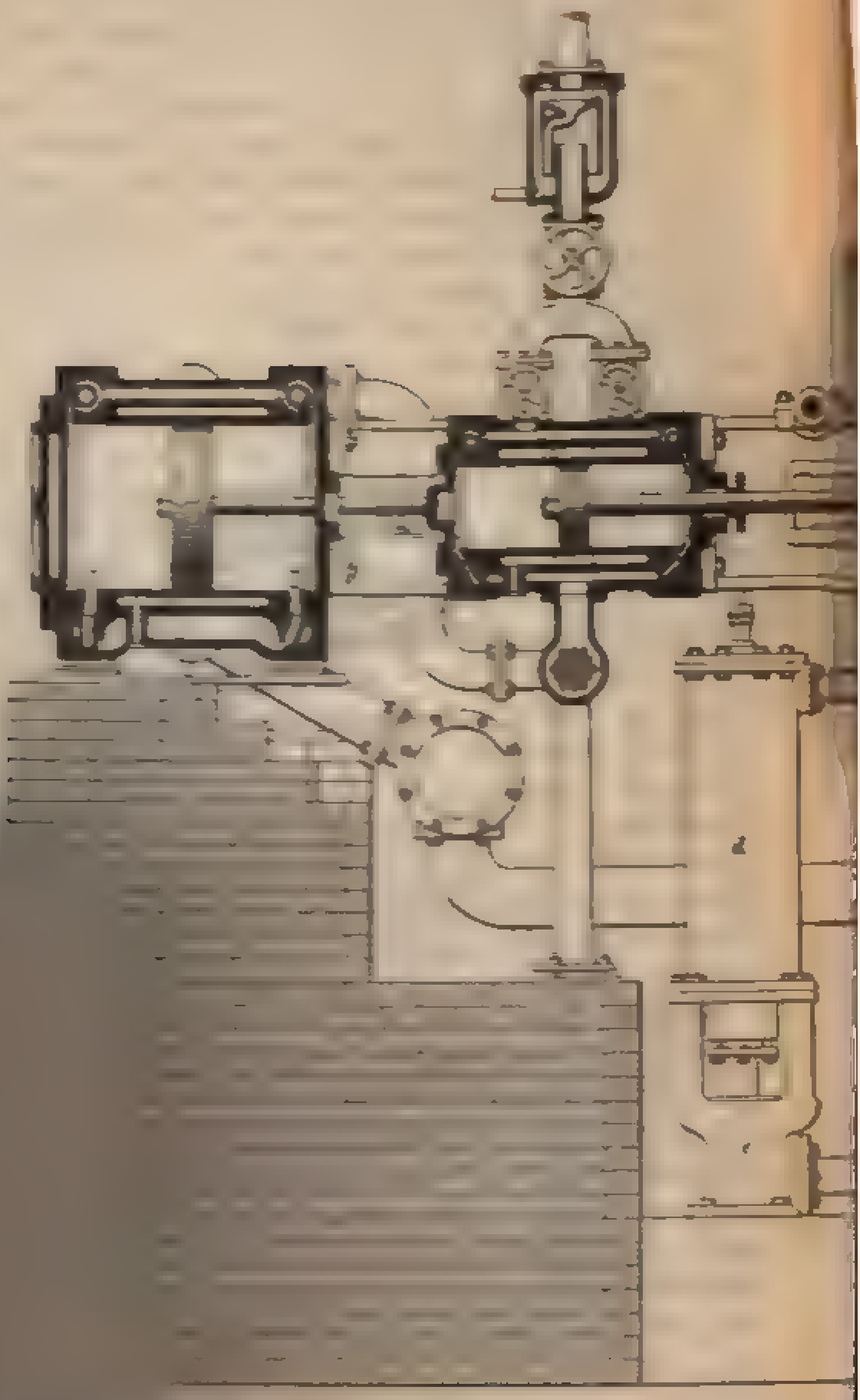
pump just when the pressure in that steam chest commences to drop, and in consequence the pressure will be kept more uniform, which results in a steady and uniform motion.

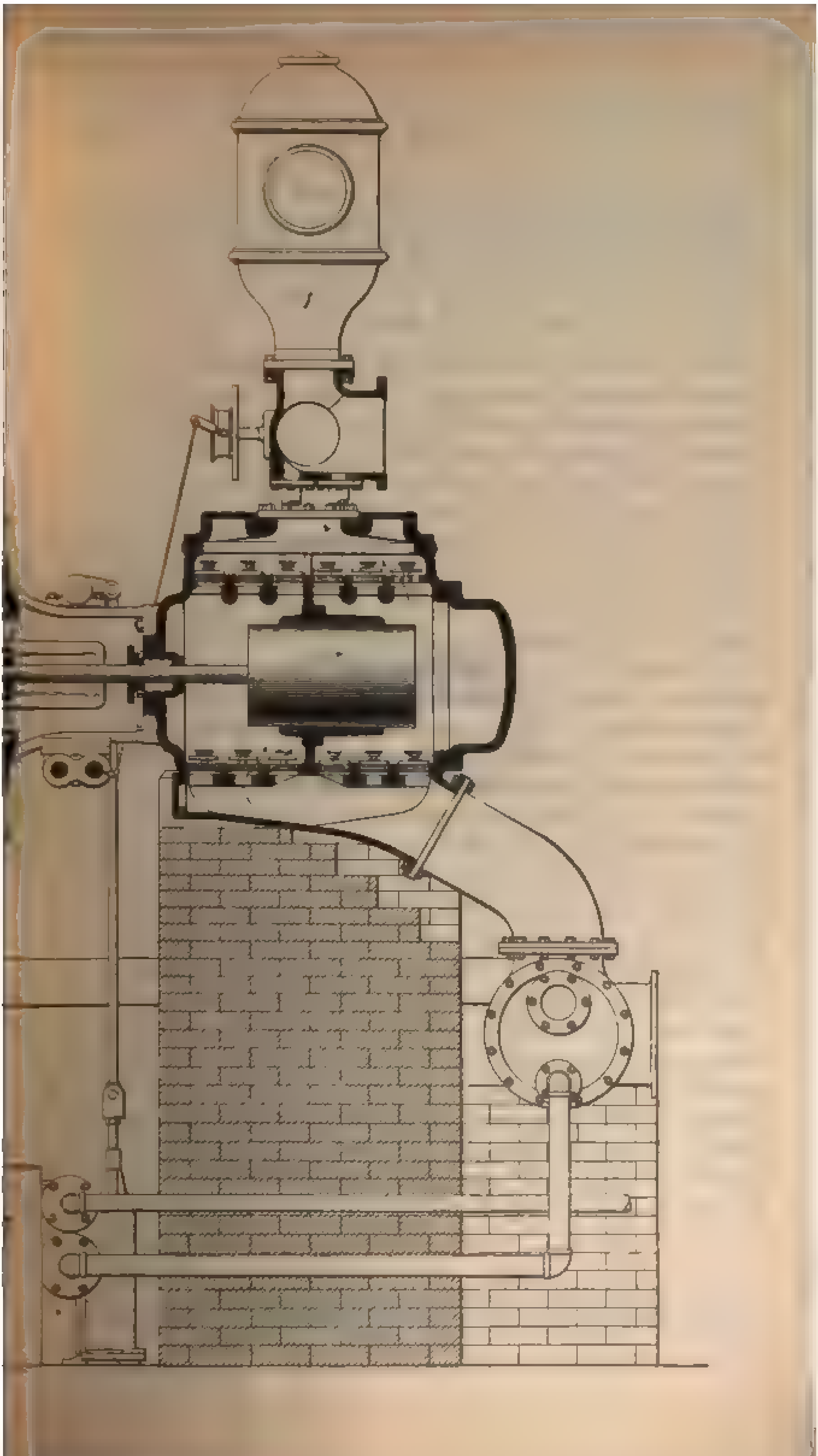
HIGH-DUTY ATTACHMENT.

35. Purpose.—The direct-acting pump, as previously stated, is one of the simplest machines for pumping liquids, but in order to work at its best requires steam at full boiler pressure to be carried to nearly the end of the stroke. In consequence, if viewed from the standpoint of steam consumption, it is a very wasteful machine. The direct-acting pump is made more economical by making it compound or triple expansion, but even with these arrangements it is not possible to secure the high ratios of expansion which are necessary for extreme economy in the use of steam, and hence of fuel, and which are demanded in large pumping plants for commercial reasons. In the ordinary steam engine, and also in the flywheel pattern of pump, power is stored up in the flywheel at the beginning of the stroke and given out when expansion begins, in order to have a uniform turning of the engine shaft, or a nearly uniform force acting upon the water piston in case of a pump. In a direct-acting steam pump, however, there are no heavy moving parts similar to a flywheel, and hence ordinarily no uniform impelling force can act on the water piston if steam is cut off early in the stroke. This defect led to the design of the **high-duty attachment**, which is simply a device that stores up power during the first half of the stroke and gives it out again during the second half, thus allowing steam to be used expansively in the steam cylinders.

36. Construction.—The high-duty attachment in actual use was designed by Mr. J. D. Davies in 1879 and taken up and perfected by Henry R. Worthington. It is shown in Fig. 12 applied to a compound direct-acting pumping engine

fitted with Corliss valves and cutting off early in the high-pressure and low-pressure cylinders. The piston rods are arranged so as to avoid internal stuffingboxes, and, in consequence, the pistons are accessible without having to dismantle the pump. The two piston rods of the low-pressure piston and the high-pressure piston rod are attached to a common crosshead *a*, which runs in guides between the pump chambers and high-pressure cylinders. On this crosshead and opposite to each other are semicircular recesses. On the guide plates are cast two journal-boxes, one above and the other below the crosshead, equally distant from it and at the point equal to the half stroke of the crosshead. In these journal-boxes are hung two short cylinders *b*, *b* on trunnions that permit the cylinders to swing backwards and forwards in unison with the motion of the plunger crosshead. Within these swinging cylinders are plungers *c*, *c*, which pass through a stuffingbox on the end of the cylinders, and on their outer end have a rounded projection *c'*, which fits in the semicircular recesses in the crosshead. Consequently, as the crosshead moves back and forth, it carries with it the two plungers *c*, *c*, which, in turn, tilt the cylinders backwards and forwards. These swinging cylinders are called **compensating cylinders**; they are filled with water or with whatever fluid the pump may be handling. The pressure on the plunger within the compensating cylinders is produced by connecting the compensating cylinders through their hollow trunnions with an **accumulator** *d*, the ram of which moves up and down as the plungers of the compensating cylinders move in and out. The accumulator used is of the differential type; that is, it has a small cylinder *c* filled with oil or water in which its ram moves, and above it has a much larger cylinder *d* filled with compressed air. On the top of the ram of the accumulator is an enlarged piston rod carrying a piston, which fits closely in the air cylinder. From this construction it follows that the pressure per square inch on the ram of the accumulator will be the pressure of the air in the air cylinder per square inch multiplied by the ratio between the area of the air piston and the ram





of the accumulator. The ratio of these areas is made to suit the particular service for which the pump is constructed. The pressure in the air cylinder is controlled by the pressure in the main delivery pipe of the pump, as it is connected to the air chamber *f* on the main delivery pipe.

37. Operation.—The operation of the high-duty attachment will now be explained. Suppose the pump is about to begin the forward stroke. At this time the water cylinders will be turned so as to point towards the steam cylinders, with their plungers at the extreme point of their outward stroke and at an acute angle with the line of motion of the crosshead, and with the full pressure of the accumulator load pushing them against the advance of the crosshead. As the pump plunger begins its forward stroke, each forward movement it makes changes the angle of the compensating plungers, until at mid-stroke the two plungers will stand exactly opposite each other and be at right angles with the pump plungers, in which position they can neither retard nor advance the movement of the plunger. Now, as the pump plunger passes the mid-stroke position, the compensating plungers begin to push the pump plunger along, whereas before and up to mid-stroke they resisted the movement of the pump plunger. This force increases constantly, until at the extreme end of the forward stroke, and when the compensating plungers are, as at beginning, at their most acute angle, they exert their greatest force in helping to aid the pump plunger in its outward movement. The return stroke of the pump is made under precisely the same conditions as the forward stroke. It is readily seen that at the beginning of the stroke and up to mid-stroke, work is being done in pushing the compensating plungers inward, and that after the crosshead passes the mid-position, work is being done by the compensating plungers. The effect of this is a nearly uniform force on the pump piston with a varying pressure in the steam cylinders.

38. An important feature connected with the use of the compensating cylinders is that the results obtained by their

use are independent of the speed, in which respect their action is better than that of a flywheel. The high-duty attachment in some respects also acts as a safety device, comparing its action here with that of a flywheel.

FLYWHEEL PUMPING ENGINES.

COMPARISON.

39. Although direct-acting steam pumps cannot be excelled in simplicity, low first cost, and small expense for repairs, yet they can never be extremely economical in their use of steam, even when built compound and triple expansion. While there is little doubt that a high-duty attachment will greatly increase the economy, the fact remains that at present only a limited number thus fitted are in use, and the above statement holds good for direct-acting steam pumps of the ordinary design.

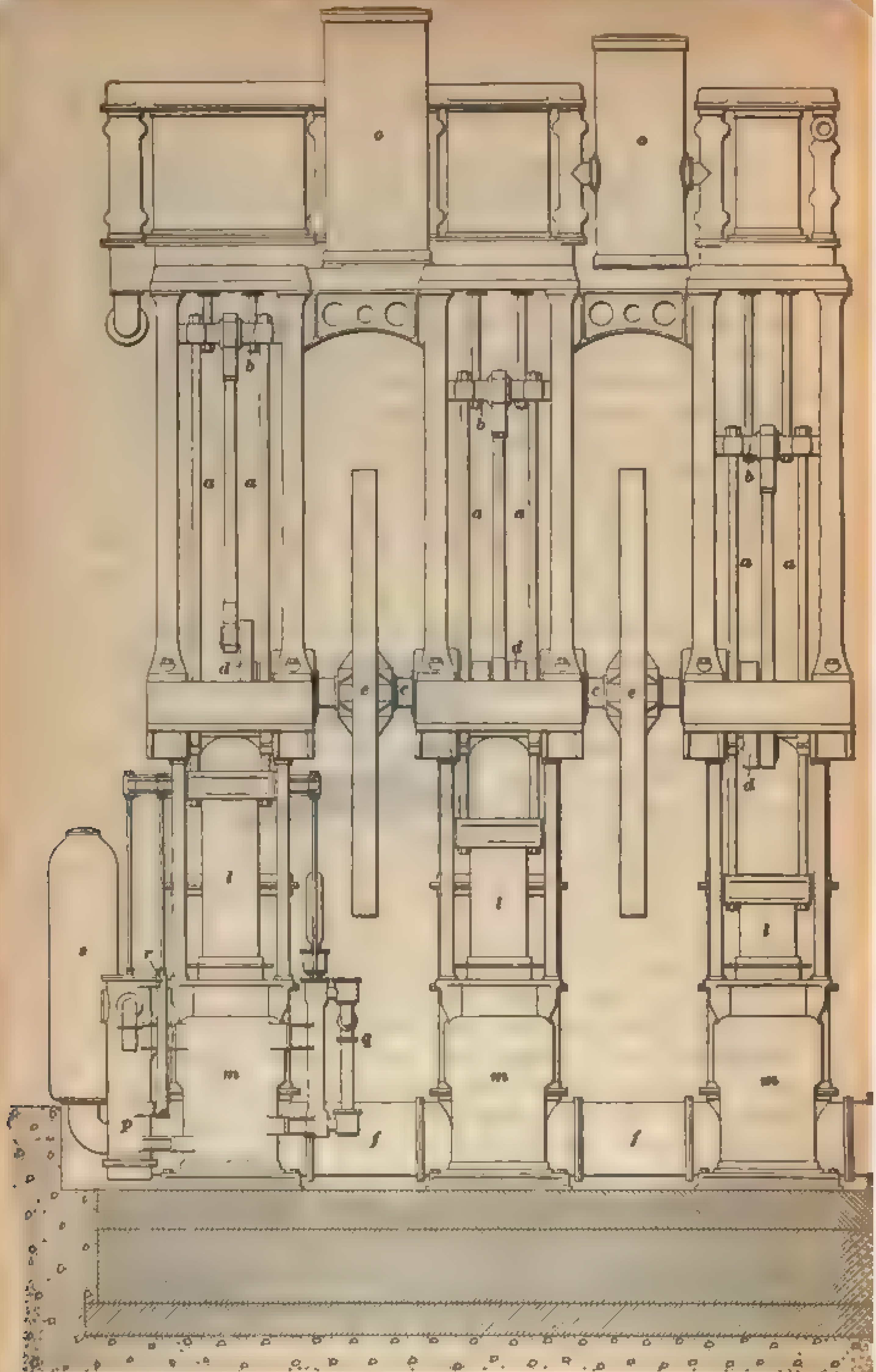
40. In large pumping stations and in many other cases where the cost of fuel is of more importance than the advantages gained from direct-acting pumps, flywheel pumping engines are often used. These are steam engines with cranks and flywheels usually designed for the particular purpose of driving the pump to which they are attached. The steam valves are driven in the ordinary way by means of eccentrics, or some approved automatic valve gear may be used to operate them. By the use of the flywheel, steam may be cut off at the most economical point in the stroke, and the surplus energy imparted to the steam piston during the first part of the stroke will be stored in the flywheel, to be given up towards the end, thus furnishing a nearly uniform driving force for the pump, piston, or plunger.

EXAMPLES OF FLYWHEEL PUMPING ENGINES.

41. Fig. 13 shows a section of one side of a *Holley-Gaskill* compound pumping engine. The engine is double, the other side being like the one shown in the figure, the

two engines having a common flywheel and crank-shaft, with cranks set 90° apart. The high-pressure cylinder is placed directly over the low-pressure, with short passages between them. The connecting-rods from the two cylinders are attached to the opposite ends of a short walking beam *B*. By this arrangement the pistons move in opposite directions and the exhaust from the high-pressure cylinder passes directly to the low-pressure one. The valves are of the Corliss type, with a releasing gear for regulating the cut-off in the high-pressure cylinder. The connecting-rod that actuates the crank is attached to the upper end of the walking beam, and the rod that works the pump plunger *P* is attached to the crosshead of the low-pressure piston.

42. Fig. 14 is a front and side elevation of a modern high-duty triple-expansion pumping engine erected at the North Point pumping station, Milwaukee, Wisconsin. The engine is of the vertical inverted three-cylinder type, having the pumps in line with the cylinders, and is condensing, the condenser not being shown. Each piston is connected to a separate outside-packed single-acting plunger by means of pump rods, as *a*, *a*. There are four pump rods to each plunger, which are joined to the steam crossheads *b*, *b* and straddle the crank-shaft *c* in such a way as to allow the cranks *d*, *d* to rotate freely between them. Two flywheels *e*, *e* are employed to give uniform rotation to the machine. In the figure, *f* is the suction pipe; *g* is the delivery pipe, the delivery from each chamber being connected to a common delivery main not shown in the illustration; *h* is the air chamber; at *i* are the suction valves; at *k* are ivery valves; *l*, *l* are the plungers and *m*, *m* the pump rs; *n* is one of the valve chambers, the upper part of orms the delivery air chamber *h* and also supports its of the bedplates. The rear of the bedplates is ted on the masonry foundation. The steam cylin- are provided with Corliss inlet and exhaust valves on igh and intermediate cylinders and Corliss inlet valves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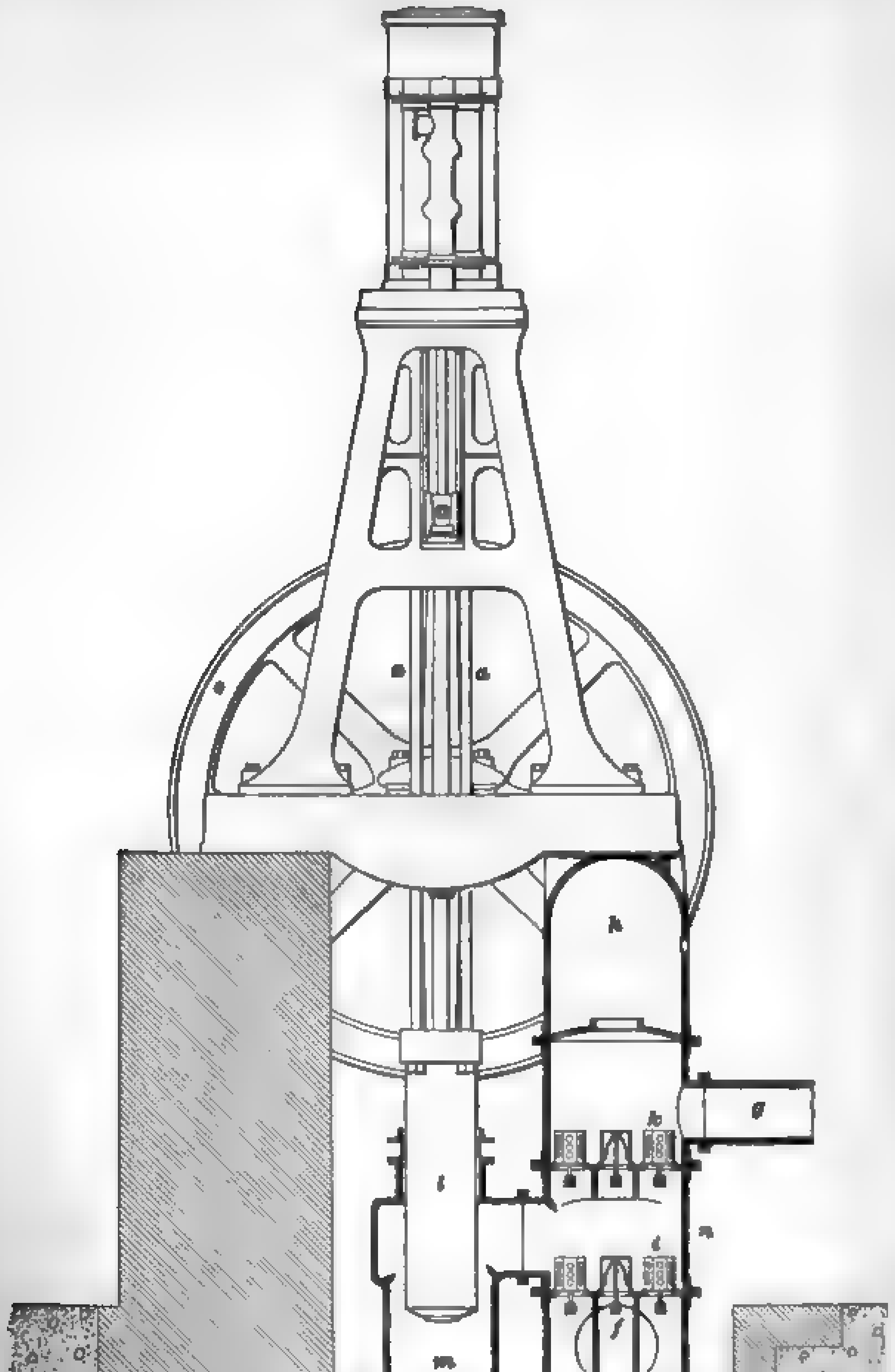
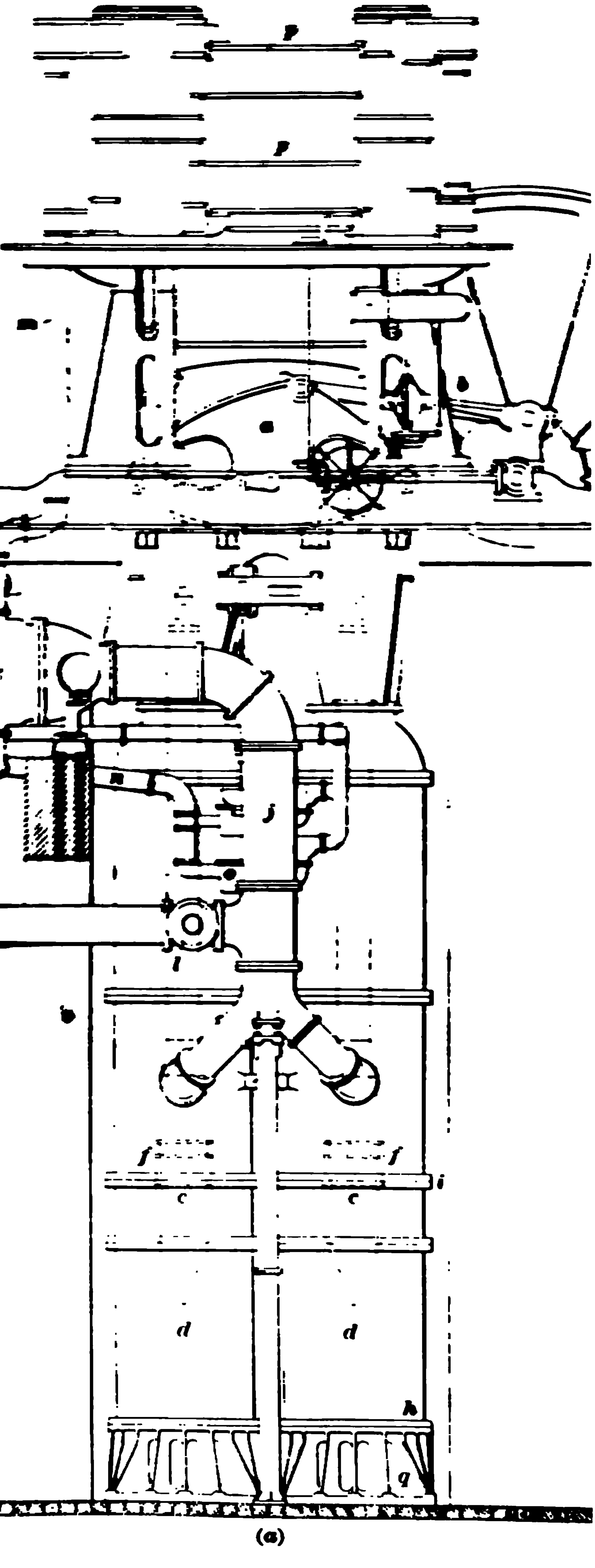
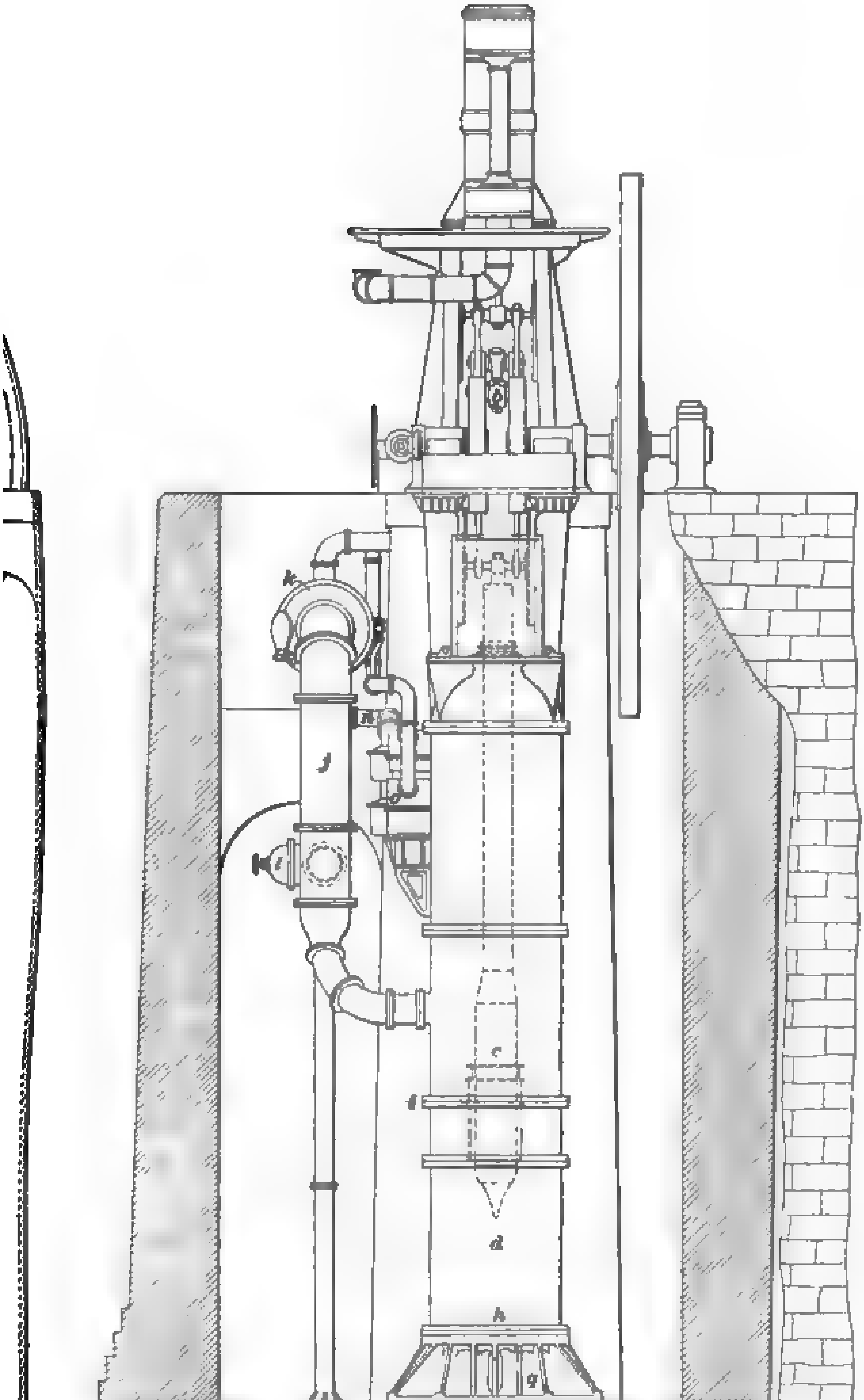




(a)



(b)

and poppet exhaust valves on the low-pressure cylinders. Large reheating receivers *o*, *o* are used between the high and intermediate cylinders and between the intermediate and low-pressure cylinders. An air pump *p* is driven directly from the plunger crossheads and serves to remove the water of condensation, etc. from the condensers. An air-charging pump *q* pumps a small quantity of air into the water in order to replenish the air supply in the air chambers. A jacket drain pump *r* drains the water from the steam jackets. A suction air chamber *s* is fitted to the extreme end of the suction pipe and prevents shocks.

43. Pumps of the design shown in Fig. 14 are used almost exclusively for high-duty municipal water-works service and are extremely economical. This type of pump has given a duty as high as 160,000,000 foot-pounds of work done per 1,000,000 British thermal units supplied to the engine.*

44. Fig. 15 shows another type of high-duty municipal pumping engine, Fig. 15 (*a*) being a side elevation and Fig. 15 (*b*) the end elevation. This pump is of the crank-and-flywheel type; the motion of the pistons is not converted into a rotary motion in the manner shown in Fig. 14, but through the intervention of a rocking beam *a*, which is rocked back and forth by the high- and low-pressure piston and is connected to the crank and flywheel by the connecting-rod *b*. This design, from its designer, is known as the **Leavitt** design. Pumps of this type have rather more parts than the type shown in Fig. 14, but they are not so high and are more accessible. The pumps are of the plunger type and are inside-packed; in the illustration, *c*, *c* are the plungers, *d*, *d* the pump chambers, and *f*, *f* the inside plunger packings. The tops of the pump chambers form delivery air chambers. The suction valves are located

* The **duty** of a pump is a measure of its performance. It will be explained in detail later.

at *h* and the delivery valves are at *i*; the delivery pipe *j* discharges the water through the surface condenser *k*, thus using the delivery water for condensation. A butterfly valve *l* controls the amount of water passing through the condenser *k*. The exhaust pipe *m* from the low-pressure cylinder enters the top of the condenser; the pipe *n* leads from the condenser to the air pump *o*. This pump is double-acting and is driven from an arm attached to the beam *a*. Two reheating receivers *p*, *p* are used to heat the steam from the high-pressure cylinder during its passage to the low-pressure cylinder. The lower ends of the pump chambers rest directly on the bottom of the pump well, which is open to the river from which the pump takes its water. The water inlets are at *q* all around the base of the pump. It will be noticed by the arrangement of the connections of the steam piston and plungers to the beam that the steam pistons have considerably more stroke than the water plungers and consequently work at a considerably higher speed, which is a decided advantage in many respects. This pump, which is located at Louisville, Kentucky, gave the remarkable duty of 151,672,000 foot-pounds of work per 1,000 pounds of dry steam used by the engine, which is the highest duty on record for any compound engine.

ROTARY PUMPS.

45. Numerous attempts have been made to replace the reciprocating motion of the piston or plunger as used in the ordinary pump by a continuous rotary motion. The results have been unsatisfactory in many cases, owing principally to the difficulty in keeping the moving parts from wearing very rapidly, thus soon producing leakage.

46. Fig. 16 shows one of the oldest and at the same time one of the best **rotary pumps.** It consists of a chamber *a* in which two toothed wheels, or disks, *b*, *b* revolve in the direction shown by the arrows. The teeth of one wheel fit

accurately into the spaces between the teeth of its mate; and, as the wheels revolve, each tooth acts as a piston that pushes a certain amount of water ahead of it, thus drawing the water from the lower part of the chamber to the upper part, as shown by the arrows. It is very important that the flat faces of these wheels, or disks, should be a good fit between the cover and the bottom of the casing or cylinder, and the edges of the teeth also a good fit against the sides of the casing. Most of the rotary pumps that have been at all successful have been modifications of the form just shown, the principal difference being in the number and shape of the teeth on the rotating disks. One of these modifications is shown in Fig. 17. In this case the disk *a* has two teeth, or wings, which act as pistons, while its mate *b* has two recesses into which the teeth on *a* fit. The shafts of the two disks are provided with outside gearing that makes their relative motion positive and always keeps them in their proper relative position.

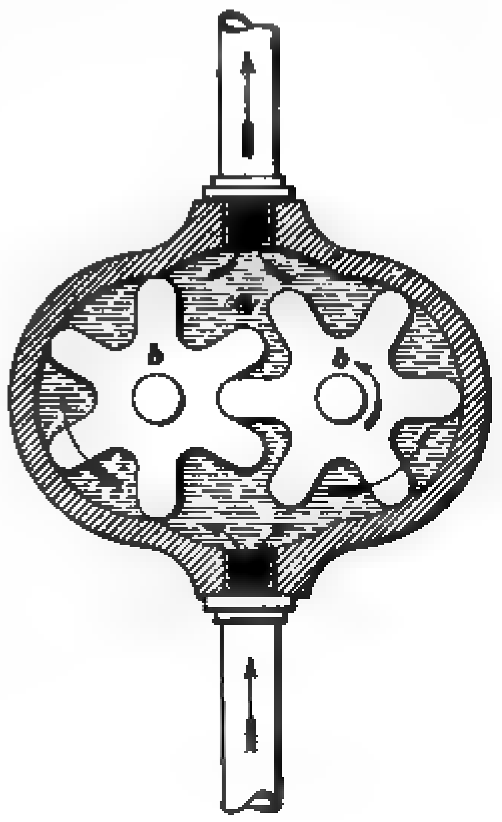


FIG. 16.

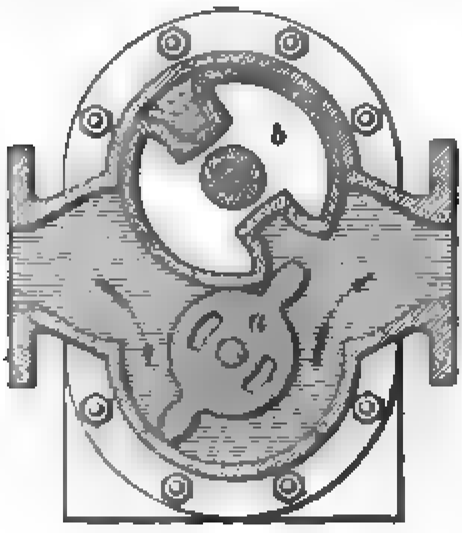


FIG. 17.

47. Fig. 18 is another modification of the rotary pump shown in Fig. 16 and gives a sectional view of **Root's cycloidal** rotary force pump. The shape of the disks or **impellers** *a*, *a* is such that the working surfaces when in contact roll upon each other. The sides of the casing are

semicircular and the impellers fit closely. The bearings in which the impeller shafts *b*, *b* run are adjustable in all

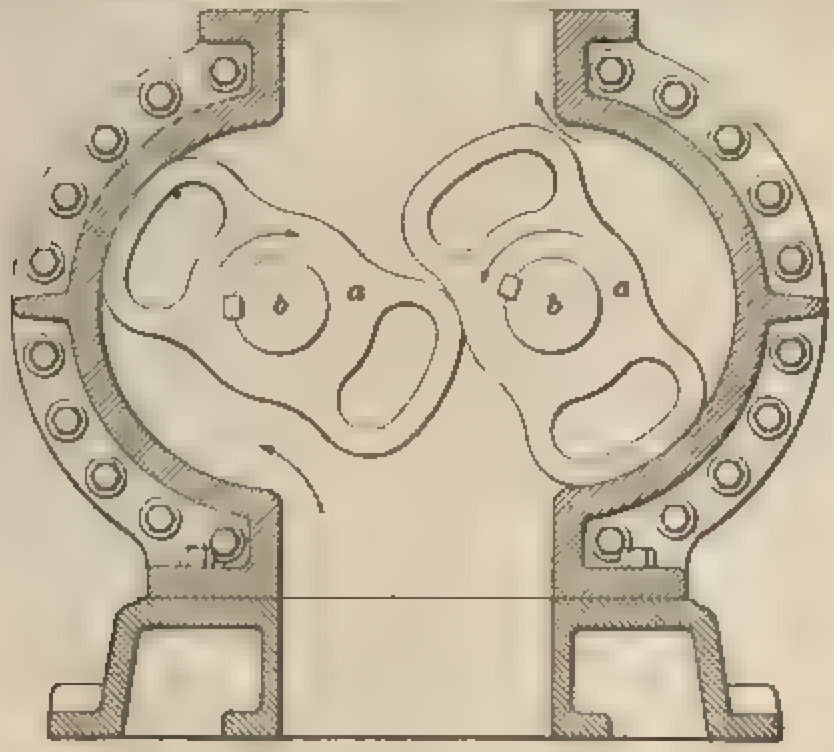


FIG. 18

directions by means of wedges. This is claimed to be the simplest and most satisfactory rotary pump yet produced.

48. The **Quimby screw pump** shown in Fig. 19 is a rather peculiar form of a rotary pump. There are two

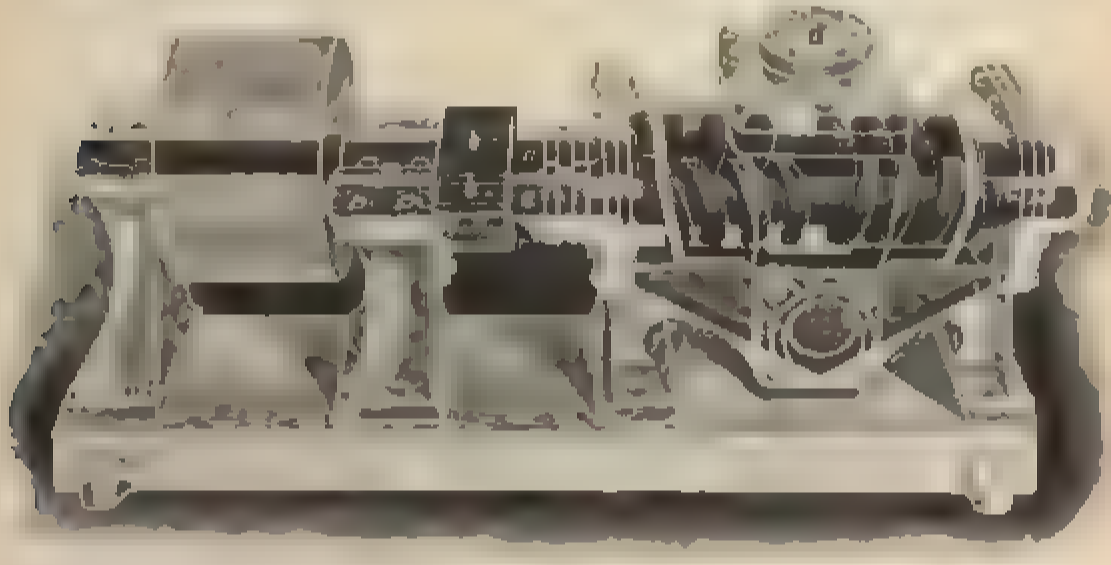


FIG. 19

shafts *a*, *a* side by side and connected by the gears *b*, *b*. Each shaft carries a right handed and a left handed screw,

and the right-handed screw of one shaft meshes with the left-handed screw of the other shaft. The water coming through the suction pipe attached at *c* flows through passages in the casing to the outer ends of the screws and is drawn towards the center by the revolving screws, from whence it is discharged through *d*. The screws closely fit the pump casing and are a close running fit on each other. Since the screws are right-handed and left-handed and the course of the water is towards the center from the end of the four screws, there is no end thrust. The pump may be driven by a belt placed on the pulley *e*, or an engine or electric motor may be connected directly to it.

CENTRIFUGAL PUMPS.

49. Centrifugal pumps depend for their action on the pressure produced by the centrifugal force of a quantity of water rotated rapidly by the vanes of the pump. Fig. 20 shows two sectional views of a centrifugal pump and clearly shows its construction. The water flows through the suction inlet *a* into the chamber *b*, thus delivering the water to the inner ends of the vanes *c*, *c*, which revolve in the direction of the arrow. When the vanes are revolved, the air between them is driven out by centrifugal force, thus forming a partial vacuum. Water is forced in through the suction pipe by the pressure of the atmosphere and fills the space between the vanes. The water, of course, is made to revolve with the vanes, and the action of centrifugal force drives it outwards into the spiral-shaped passage *d*, which leads it to the discharge pipe connected to the outlet *e*.

50. Centrifugal pumps are most efficient when working under low heads and are seldom used for lifts greater than 40 feet. For low heads and large quantities of water they give excellent results, and are especially useful when the water contains grit or other impurities that would destroy the pistons and packing or prevent the closing of the valves of other pumps. Since there are no valves or other

restricted passages, centrifugal pumps have been largely used in dredging machines for pumping water containing large quantities of mud, sand, and gravel; and, in fact, anything can be pumped that will be carried through the pump and pipes by a current of water. Centrifugal pumps may be belt-driven or be direct-connected to an engine or other motor.

POWER PUMPS.

51. Definition.—Pumps in which the piston or plunger is driven by a crank that receives its motion through a belt or gearing from some outside source of power are usually called **power pumps.**

52. Single Power Pumps.—A single power pump is one in which but one pump is driven by the shaft. This pump may be either *single-acting* or *double-acting.*

53. Duplex Power Pumps.—When two pumps are driven by cranks on a single shaft, the combination is called a **duplex power pump.** The discharge branches from the two pumps are generally combined in such a way that they discharge through a single pipe; and by a proper arrangement of the cranks, the flow through the discharge pipe and the power required to drive the pumps are made nearly constant. If the pumps are single-acting and the cranks are set 180° apart, the discharge from the two pumps will be the same as the discharge from one double-acting pump with the same diameter of piston and length of stroke. Duplex double-acting pumps, with cranks set 90° apart, are much used and give a very steady discharge, since, when one crank is on its dead center and its piston, consequently, is at the end of its stroke and momentarily at rest, the other piston is moving at its maximum velocity and discharging at its maximum rate.

54. Triplex Power Pumps.—Three pumps driven by cranks on a single shaft form a **triplex pump.** The most common application consists in the use of three single-acting plunger pumps with cranks set 120° apart. With

such a combination, at least one of the pumps is always discharging and one taking water from the suction pipe, and the flow is therefore continuous and nearly uniform

55. Fig. 21 shows a type of triplex belt driven power pump much used for feeding boilers, filling elevated tanks in

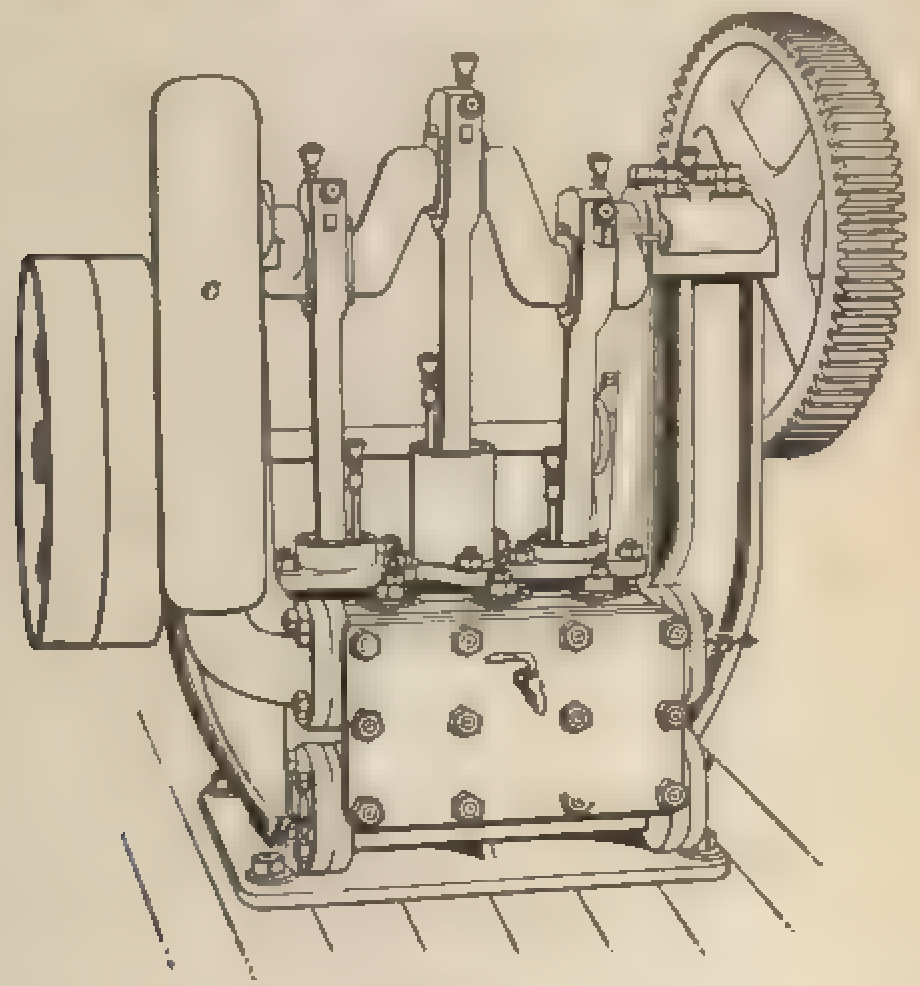


FIG. 21

buildings, supplying hydraulic elevators, etc. It consists of three single acting plunger pumps driven by cranks set at 120° on a single shaft. A tight and a loose pulley provide the means for starting and stopping the pump, without disturbing the engine or main shaft. The pulley shaft is geared to the crank-shaft by a pinion and spur wheel. *I* is the suction inlet, *D* the discharge opening, and *C* the air chamber.

56. Where the supply of power is steady, a belt-driven power pump is very convenient and economical for the purposes for which such pumps can be used, since they get their

power with the same degree of economy as the engine by which they are driven; they are also simple in construction and easily operated.

57. In locations where there is no steam or other power directly available, or where the use of the pump is so intermittent that a steam plant will not be economical, or where the cost of supplying steam is too great, power pumps driven by electric motors may be used to advantage. Small pumps driven by windmills, hot-air engines, gas engines, etc. are much used for supplying water to buildings that have no connection with public water works. Small, single-acting plunger pumps are most commonly used with these methods of driving, although double-acting pumps are sometimes used. Where water-power is available, pumps for city water works or for supplying manufacturing establishments are often driven by waterwheels.

MINE PUMPS.

SERVICE.

58. Pumps intended for the drainage of mines are probably subjected to the hardest usage of any. The water to be pumped is generally gritty and frequently it contains a large percentage of acids; a very high pressure must generally be pumped against and the pump has to run almost continuously for long periods at the full limit of its capacity. In most cases the mine is located quite remote from supplies; the pump of necessity is underground and in a rather limited space; it is generally of vital importance that the pump be kept running in order to prevent the drowning out of the mine, and for the same reason it is desirable that all wearing parts be very accessible so that repairs can be made in the shortest time. Furthermore, it is desirable that the pump continue at work even when covered entirely with

water. The exigencies of the service have led to designs of pumps especially suited for the work. While they do not differ essentially from ordinary pumps, they have generally a different arrangement of water end. Nearly all mine pumps are of the plunger pattern, the plunger pump, by reason of the ease with which leakage can be stopped, being best adapted for high pressures.

59. Mine pumps are either pit pumps, direct-acting steam pumps, or power pumps. By a pit pump is meant a pump having its water end located at the bottom of the mine and connected to a steam engine or other motor at the surface by rods. Pit pumps are the oldest type of mine pump and are still used to some extent.

TYPES OF MINE PUMPS.

CORNISH PUMPING ENGINE.

60. Until within comparatively recent times, the so-called **Cornish pumping engines** have been the only ones used for removing the water from the mines. This engine was invented by Watt for use in the mines of Cornwall and was the first really effective steam engine made. An illustration of a Cornish pumping engine is shown in Fig. 22. The cylinder *A* is single-acting; that is, the steam acts only on one side of the piston. The piston rod [illegible] is connected to the [illegible] beam [illegible] by a link [illegible]. In Cornish pumping engines the steam is admitted through the valve in *I* to the top of the piston and forces it down towards the bottom of the cylinder. The weight of the pump rods and other moving parts in the shaft, which parts are called the **pit work**, is sufficient to raise the piston to the top of the cylinder when the steam on the upper side of the piston is put in communication with the lower side. The cylinder *A* is steam-jacketed; that is, the cylinder walls are hollow and

filled with steam in a manner similar to the water-jacket of an air compressor, the steam entering through the pipe K.

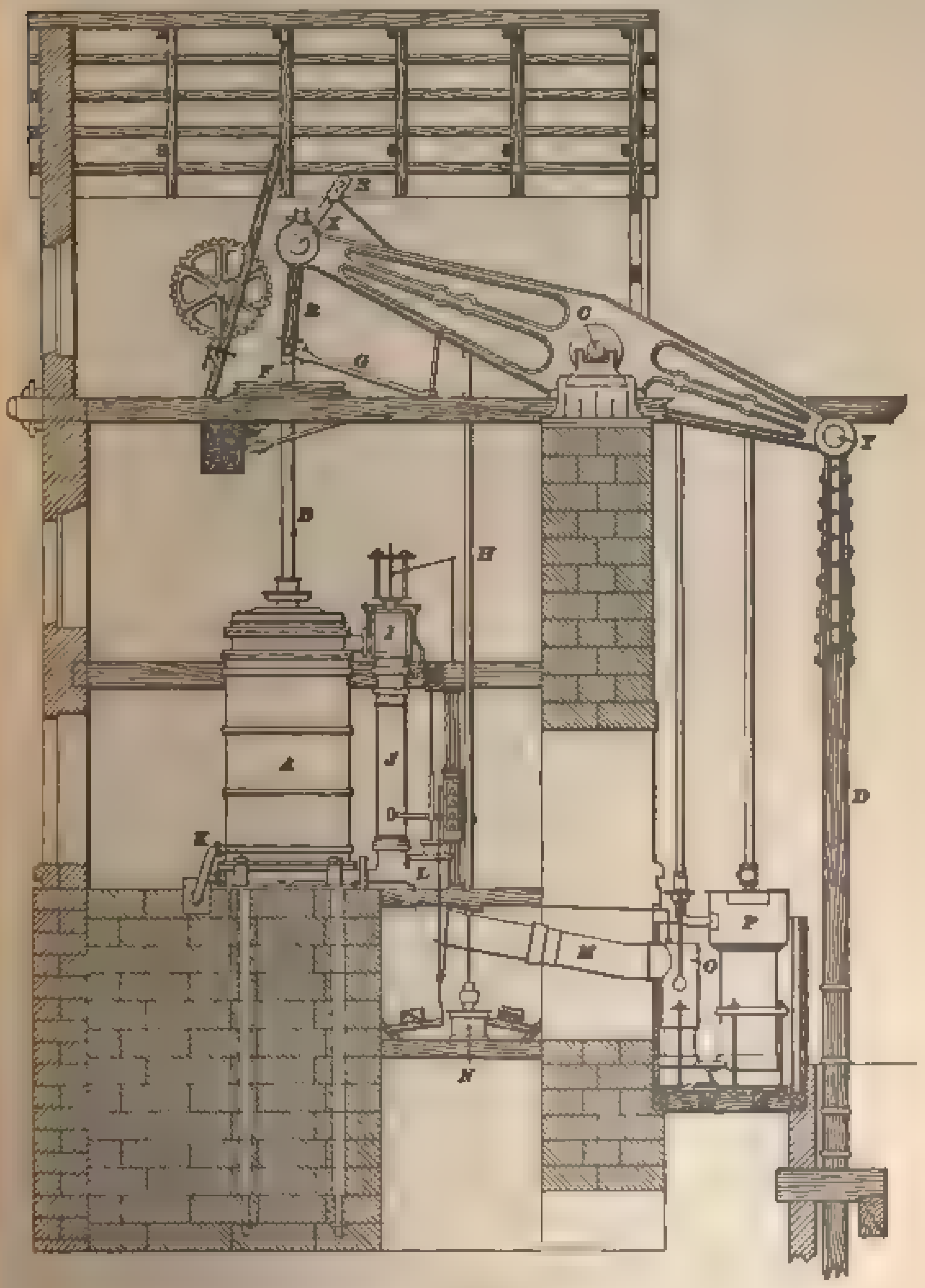


FIG. 22

61. The action of the pump is as follows: Steam is admitted to the upper side of the piston through a valve in I,

which is operated by means of a tappet rod *H*. The steam is of high pressure and forces the piston rod downwards and at the same time raises the pit work. This gathers momemtum while coming upwards, and the steam is cut off, expanding during the rest of the stroke. Just before the end of the stroke, what is termed an *equilibrium valve*, also located in the casing at *I*, opens and allows the steam in the upper end of the cylinder to communicate with that in the lower end. The two pressures being thus balanced, the heavy pit work causes the right end of the walking beam *C* to descend, raising the piston to the top of the cylinder again. The exhaust valve is located at *L*. When this is raised, the exhaust steam flows through the pipe *M* into the condenser *O*. *P* is a small pump used in operating the condenser. *E* is a catch intended to act in case the valves should fail to work. The piston rod passes between two blocks, of which *F* is one, the other being opposite. If the left end of the walking beam should descend too far, a crosspiece on the catch rod *E* is caught by the blocks *F* and prevents any further downward movement of the piston.

BULL ENGINE.

62. In Fig. 23 are shown two views of a Cornish Bull engine and pump. This style of pumping engine is made by many firms and differs but very little in regard to details. Here the walking beam is dispensed with and the cylinder is placed directly over the shaft, the pit work being attached to the piston itself. In this case also the cylinder is single-acting, the steam being admitted below the piston instead of above it, as in the engine described in Fig. 22. The condenser is usually omitted in this class of pumps, the steam exhausting directly into the atmosphere. In case the weight of the pit work should be greater than necessary to force the water up the required height, the extra weight is counterbalanced.

63. The Bull pumping engine possesses several advantages over the Cornish pump. The heavy walking beam

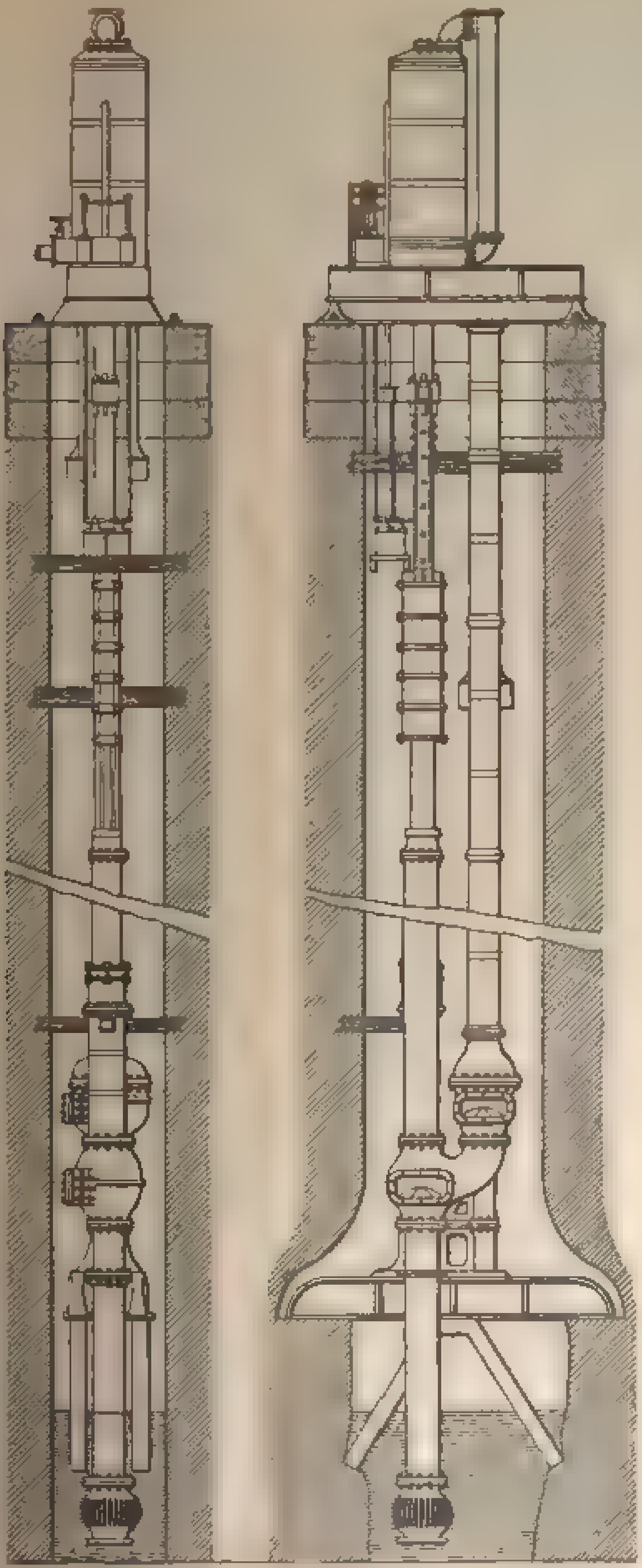


FIG. 23.

H. S. V. I

and its connections are dispensed with; this lessens the first cost; the friction is greatly reduced; the advantage of having a direct-acting engine is also obtained. The principal disadvantage is that the pump being directly over the shaft, takes up a great deal more room where space is necessary than the Cornish pump.

64. Cornish and Bull pumps both use steam expansively. They do not have flywheels to absorb the energy of the early part of the stroke and give it out again at the end, but utilize the heavy pit work to accomplish the same purpose. The number of expansions ranges from four to ten; that is, the steam is cut off from ¼ to $\frac{1}{10}$ stroke. When using more than six expansions ($\frac{1}{6}$ cut-off), the strain produced on the machinery becomes very heavy, and the resulting wear and tear of the machinery more than makes up for the increased economy in the use of steam. Many engineers claim that four expansions are the most economical.

PIT-PUMP ARRANGEMENT.

65. The arrangement of the pump driving mechanism, pit work, and balancing mechanism in a deep mine shaft is shown in Fig. [illegible]. In this case an ordinary horizontal engine is used at the surface, which works the pumps through the intervention of a gear train and a connecting-rod [illegible], the connecting-rod being attached to the bell-crank [illegible] the great weight of the rod [illegible] the weight of the plungers is [illegible] the weight of the water column; hence [illegible] be required to be used [illegible] counterbalanced. A [illegible] the bell-crank [illegible] from the shaft [illegible] and the other [illegible] means of a link and [illegible] raised by four [illegible] other three [illegible]

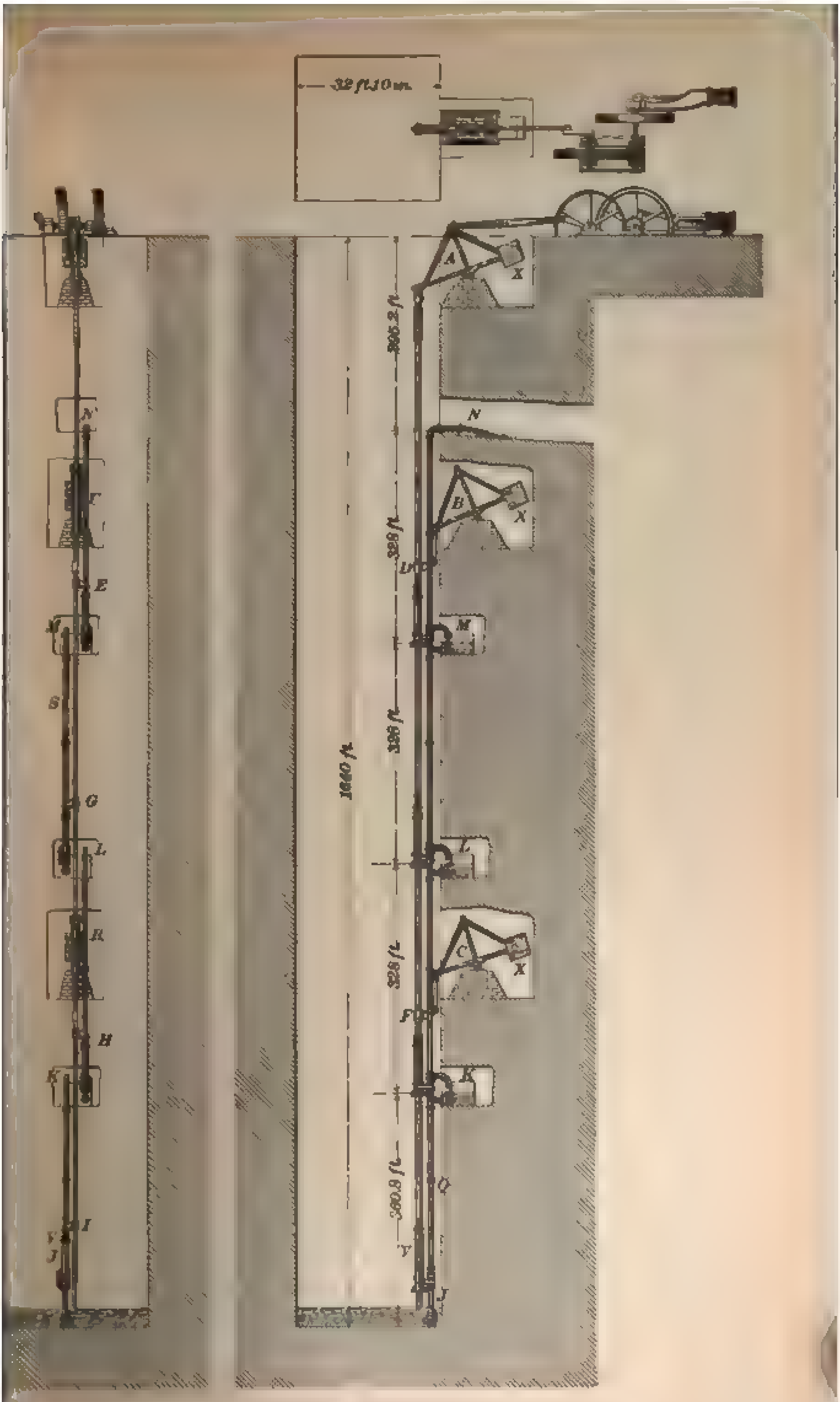


FIG. 24.

discharged into a tunnel *N*, about 300 feet below the surface. The pump rod goes straight down the shaft and the discharge pipes are placed alternately on each side of it *J* is a suction pipe. *I* is a bracket, one end of which is attached to the pump rod and the other end to the pump plunger *V*. On the down stroke, the water is forced out of the pump cylinders and up the pipes *Q*, *R*, *S*, and *U*, discharging at *K*, *L*, *M*, and *N*. The same pit work and pump arrangement may be and is used for Cornish and Bull pumps.

66. The use of a geared engine possesses several advantages over the Cornish or Bull pumping engines The flywheel permits a more even distribution of the power The length of the stroke is always the same, and there is no danger of damage caused by the piston being blown through the cylinder head, should the valve gear refuse to work.

WATER END OF PIT PUMPS.

67. Comparison of Lifting and Force Pumps.—The water end of a pit pump may be a lifting pump or a force pump The lifting pump is generally considered inferior to the force pump (which latter is almost invariably of the plunger pattern) for mine work.

It is easier to specify the objections to lift pumps than to state their advantages over the plunger pumps The pump rod, being necessarily inside of the delivery pipe, reduces the effective area of pipe and increases the friction of the water to some extent, owing to the added surface rubbed against. The rods are concealed and cannot be inspected without removing the entire rod. Not only do the bolts and rods sometimes break, thus rendering their recovery difficult, but the bolts will wear against the stocks, causing loss of power by friction and destroying the pipes. Lift pumps are not so liable to sudden injurious strains as the plunger pumps.

The plunger type of pumps is superior to the lift pump in nearly every respect for very high lifts with the accompanying heavy pressure or when dirty water is being raised.

When pumping against a heavy pressure, it is impossible to keep the piston of lift pumps tight and prevent the water from leaking. The piston and cylinder of the lift pump must in every case be a perfect fit and be truly cylindrical. With plunger pumps, on the contrary, the rod passes through a stuffingbox, and the plunger may or may not fit the cylinder. When pumping dirty water, the grit comes in contact with the surface that the piston of a lift pump is constantly traveling over and destroys both the cylinder and piston very rapidly; whereas, the plunger has to be kept tight at only one permanent place, and the dirt cannot very well get at the surface of the packing on which the plunger or plunger rod rubs. Every part of a plunger pump can be readily examined and repaired without being obliged to take down the whole apparatus.

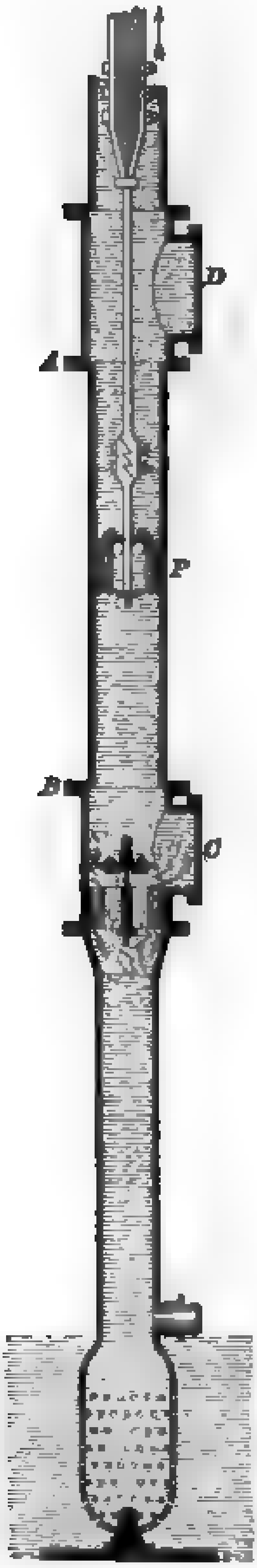


FIG. 25.

68. Example of a Lifting Pump. In Fig. 25 is shown a section of a lifting pump for use in mines. The pump consists of a series of pipes connected together, of which the lower end only is shown in the figure. That part of the pipe included between the letters A and B forms the pump cylinder in which the piston P works. The part above the highest point of the piston travel is the delivery pipe, and the part below the lowest point of the piston travel is the suction pipe. When speaking of these parts as applied to mine pumps, the delivery pipe is usually termed the **working barrel,** and the suction pipe the **wind bore.**

In mine pumps, the lower end of the wind bore is pear-shaped and perforated

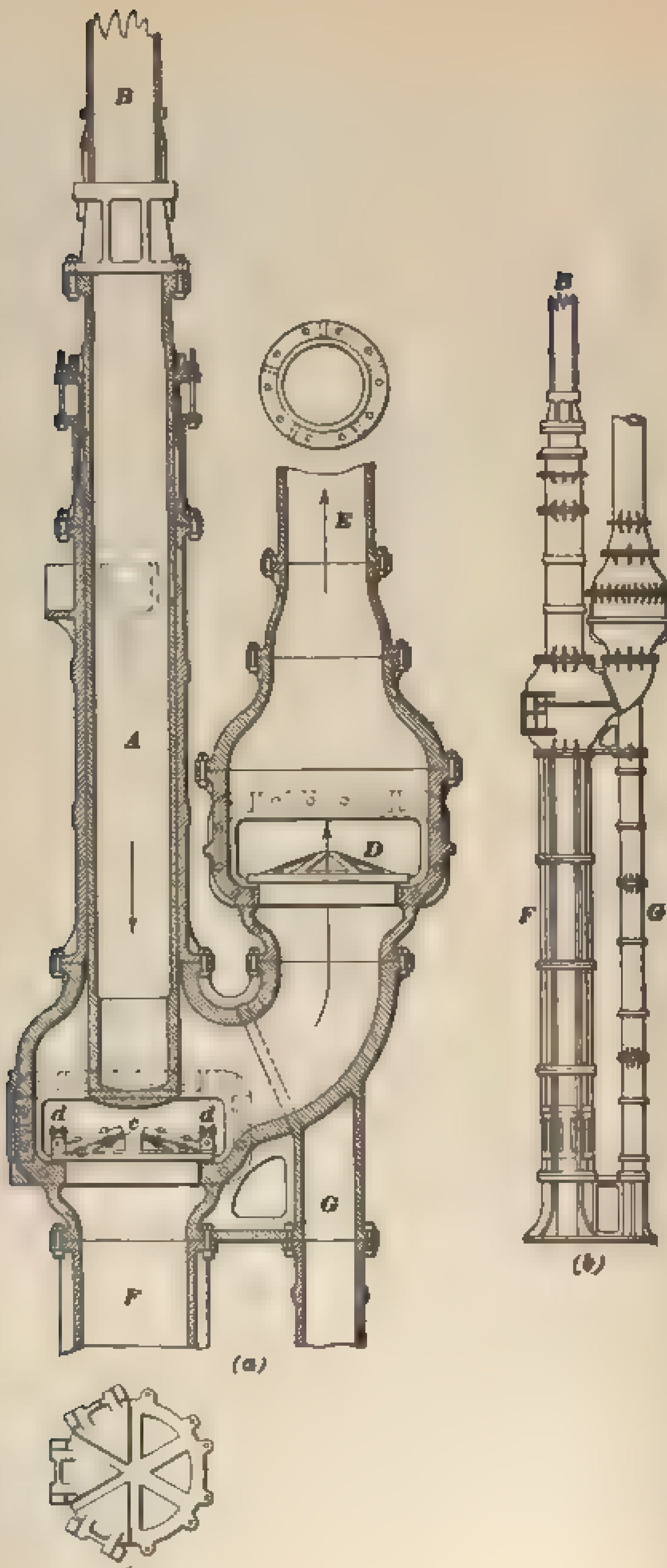


FIG. 26.

with many small holes to keep solid matter in the water from entering the pump and destroying the valves. In some cases, the pear-shaped end is covered with gauze for the same purpose. A bonnet *C* may be removed to allow the suction valve to be repaired, and a bonnet *D* gives access to the piston and its valves. The pump rod is made of wood strapped with iron and is connected to the piston in the manner shown by the illustration.

69. Example of a Force Pump.—Fig. 26 shows one design of a force pump of the plunger type as used for a pit pump, Fig 26 (*a*) being a section showing the pump cylinder and valves, and Fig. 26 (*b*) showing an elevation of the whole water end drawn to a smaller scale. The plunger *A* is hollow, the weight of the heavy rod *B* and connections being sufficient to raise the water to the required height. Suppose the plunger to be on the down stroke; the valve *c* is then closed and the water filling the pump cylinder is forced through the valve *D*, which it opens, and up the delivery pipe *E*. When the plunger reaches the end of its stroke and begins its return, the weight of the water forces the valve *D* to its seat, retaining the water above it in the discharge pipe *E*. As the plunger moves upwards it leaves a partial vacuum behind it, causing the water to rush up the suction pipe *F*, lift the valve *c*, and fill the pump cylinder. The plunger makes another downward stroke and the above process is repeated. A support *G* is attached to the delivery pipe, the lower end resting on a foundation. This is necessary, since the great weight of the water in the discharge pipe and the weight of the pipe itself would break it off at the bend unless supported in some such manner; otherwise, the thickness of the metal around the bend would necessarily be enormous.

70. A top view of the valves is shown in Fig. 26 (*c*). They consist of six triangular valves arranged in a circle, with their apexes pointing towards the center. These six valves turn upwards on hinges and are prevented from going too far by the projection *d*; see Fig. 26 (*a*). Three

of the valves have been removed so as to show the amount of valve opening that they give. When the valves are open, they form an angle of about 45° with their position when closed.

SINKING PUMPS.

71. Purpose.—When putting down a new shaft or deepening an old one, the so-called **sinking pump** is used to drain the water from the shaft bottom so that the work may proceed. These pumps must necessarily be portable and are suspended by a chain attached to eyebolts in the pump. They are also provided with wrought-iron clamps, by means of which they may be attached to the timbers in the shaft when [illegible] to fix them in position temporarily. Hence, as the shaft gets deeper, the chain may be lengthened [illegible] placed on the upper end of the [illegible] The sinking pump [illegible] the hardest usage of any mine pump. The water pumped is [illegible] gritty and often acid. [illegible] from the pump from above [illegible] completely covers the [illegible] at times from the soil itself. [illegible] pump must work [illegible] its capacity, [illegible] its [illegible] may flood shaft [illegible]

72. [illegible] a Cameron sinking [illegible] the conditions [illegible] with mine [illegible] mechanism whatever [illegible] the pump self [illegible] prevent the pump [illegible] suspending it [illegible] method of pumping [illegible] nearly the [illegible] secure

of the pump is given in the figure. The pump has one plunger, but is double-acting by reason of its peculiar construction. It will be noticed that leakage past the plunger *A*

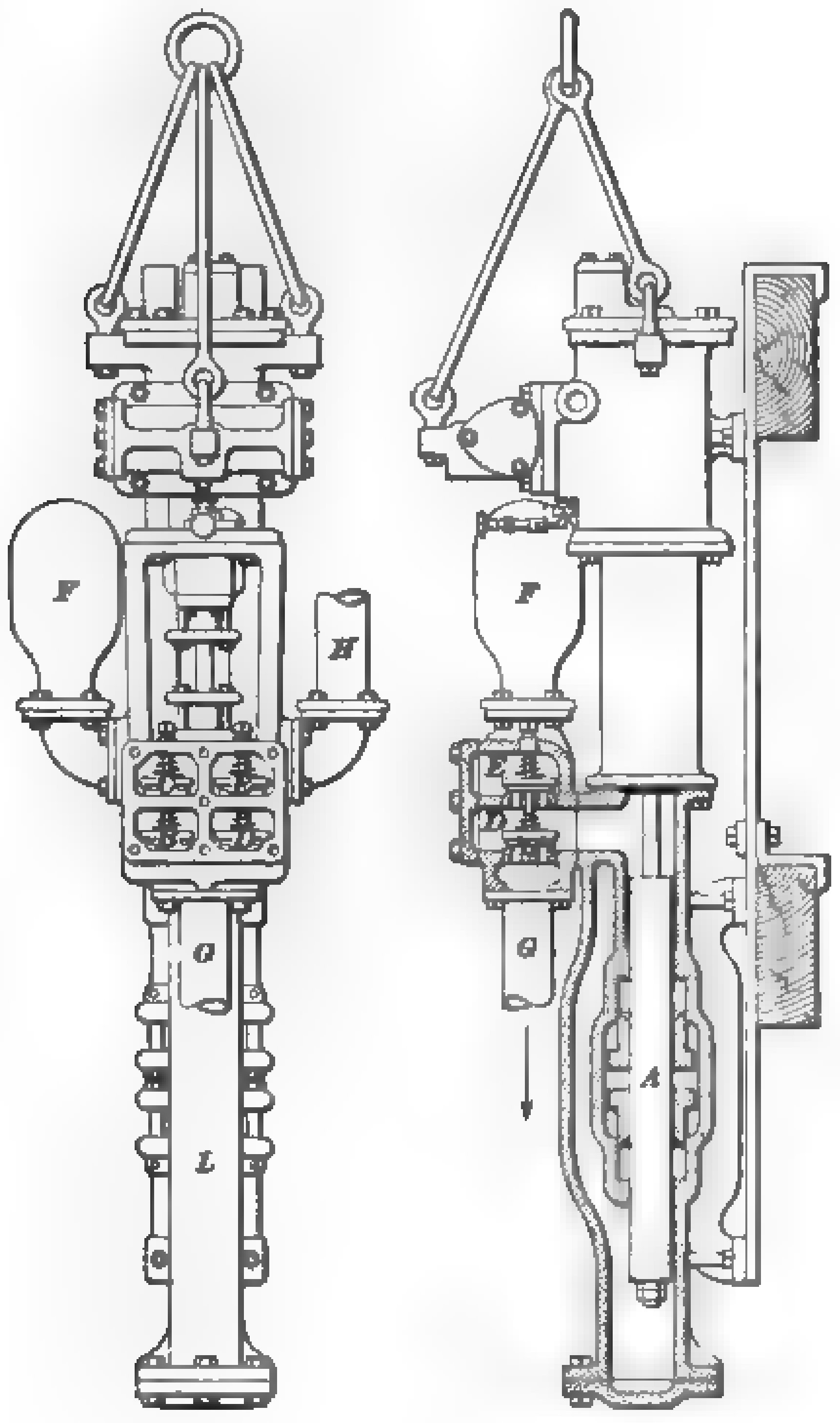


FIG. 27.

is prevented by two stuffingboxes and glands placed in the center of the pump cylinder; a pump having this arrangement is said to be **center-packed.**

The action of this pump is as follows. Suppose the plunger to be moving downwards. The water is forced out of the chamber *L*, which communicates with the delivery pipe *H* by means of the valve *C*, and lifts *C*, thus flowing into *H*. As the plunger moves down it leaves a vacuum behind it; the water in the shaft rushes up the suction pipe *G*, raises the valve *D*, and fills the upper part of the plunger cylinder. When the stroke is reversed, the valves *C* and *D* close, and the valves *E* and *B* open, the water being forced up the pipe *H* through the valve *E*, and the chamber *L* is filled through the opening of the valve *B*. *F* is the air chamber. The section shown by the view on the right is taken in a rather peculiar manner, the greater part being taken through the center line of the engine so as to show the plunger, stuffingboxes, etc., and the part showing the valves being taken on the center line of the valves *E* and *D* of the view on the left

73. Electric Sinking Pump.—While most sinking pumps are steam-operated, electrically driven sinking pumps are also used. Fig. 28 shows a duplex electric sinking pump of the center-packed type, the stuffingboxes being shown at *H*. The two plunger rods *E* and *F* operate the plungers. A clamping piece *D* is used for attaching the pump to the shaft timbers; an eyebolt *G* is used for suspending the pump from a chain. The water enters through

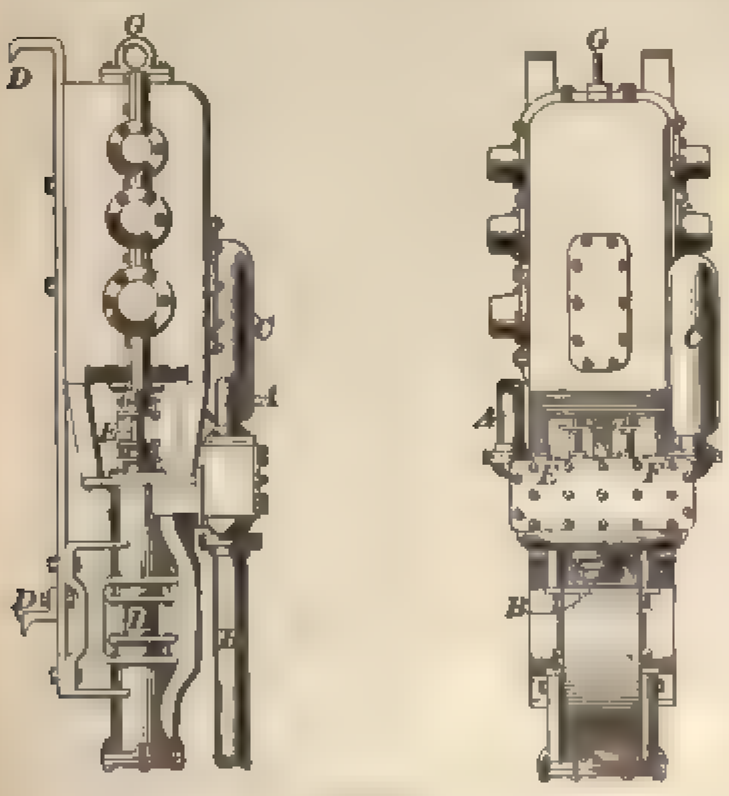


FIG. 28

suction pipe *B* and leaves through the discharge pipe *A*.

An air chamber C is fitted to the valve chamber. The electric motor is within the water-tight casing above the water end and is protected by it, so that the pump can work just as well under water as above it.

DIRECT-ACTING STEAM PUMPS FOR MINE WORK.

74. Pumps Used.—Direct-acting steam pumps used for mine drainage are almost invariably of the plunger pattern. Most of them are duplex, but a number of single double-acting steam pumps are in use. Formerly, all the mine steam pumps were simple direct-acting pumps, but of late years compound and even triple-expansion pumps have grown in favor, and even crank-and-flywheel pumps driven by compound Corliss engines are now extensively used on account of their superior economy. Most of the pumps are of the *double-plunger type*, there being two plungers to each water cylinder, and the stuffingboxes are located on the outside, thus making the pumps *outside-packed.* Some mine pumps are *center-packed* and use but one plunger for each water cylinder.

75. Simple Double-Plunger Pump.—Fig. 29 shows a side view of a simple direct-acting single mine pump of

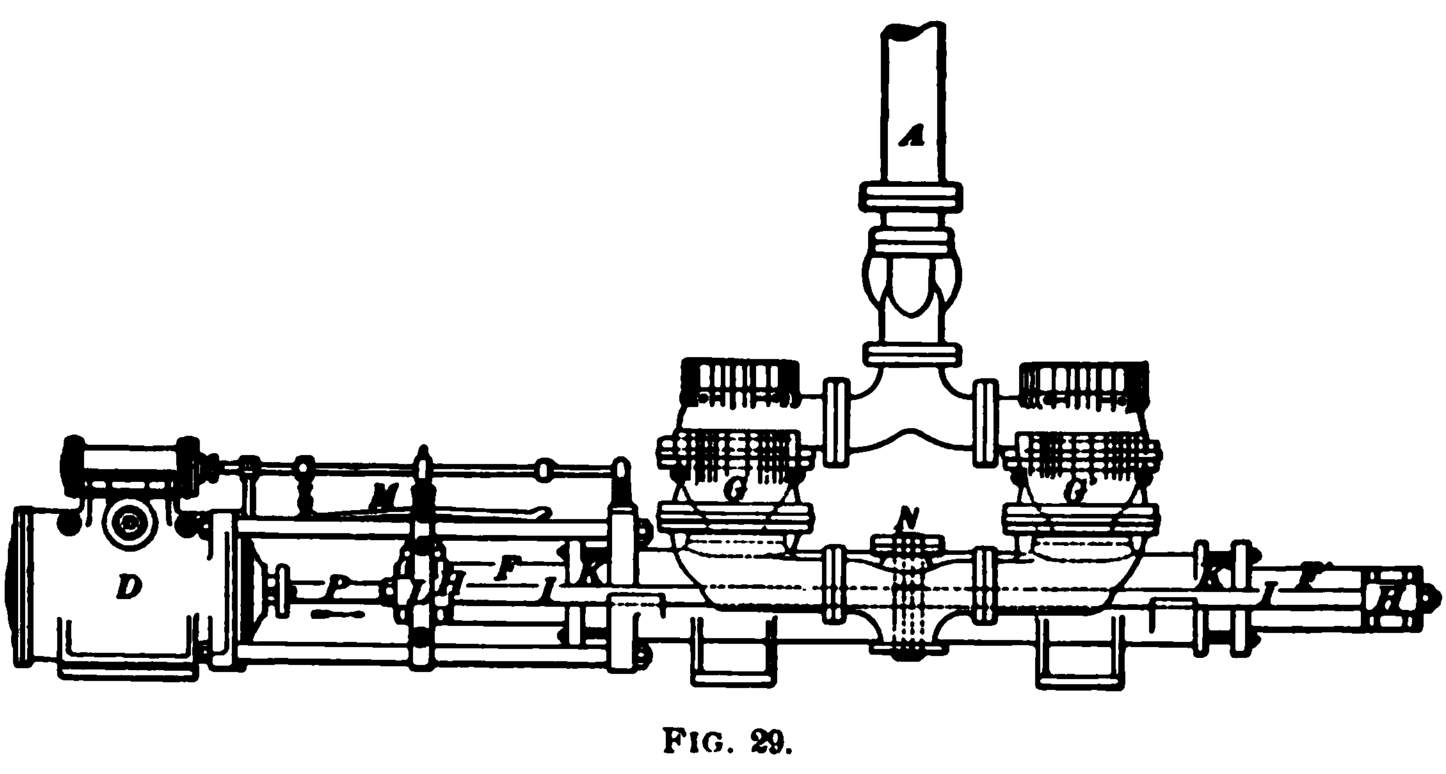


FIG. 29.

the double-plunger type. The two plungers F and F' carry yokes H, H at their outer ends and are tied together by

side rods, as I. The plunger F is attached directly to the piston rod P. Suppose the steam piston in D to be moving to the right; the plunger F is then forcing water into the chamber G and up the discharge pipe A. Since the plunger F is moving out of the water cylinder (it will be understood that the cylinders in which F and F' work are divided by a water tight partition at N), water flows in through the suction pipe, and when the pump makes its return stroke, F' does the forcing while water flows into the cylinder in which F works. It is thus seen that by the use of two plungers connected as shown, the pump is made double-acting. Stuffingboxes K and K' are used for packing the plungers.

76. Compound Double-Plunger Pump.—The internal arrangement of a double-plunger pump is shown clearly in Fig. 30, which is a sectional view of one side of a Jeanesville compound duplex mine pump designed for heavy pressures. The section shows one of the plungers E working inside its chamber; G is the partition that separates the two chambers. The outer end of each plunger is supported by a shoe K working on a slide I. L is the suction pipe with branches leading to the suction valve chambers F, F; the discharge valve chambers H, H connect with the discharge pipe shown just over the pump cylinders. As shown in the figure, there are two suction and two discharge valves for each plunger. The usual arrangement for pumps of this size is to have a great number of small valves instead of a few large valves, as shown, but for mine work the sulphur in the water destroys the valves rapidly and the large valves are more quickly and cheaply replaced. A is the main and B the auxiliary throttle; C is the high-pressure cylinder, from which steam goes to the low-pressure cylinder through the pipe D. The valve gear of the steam end is practically the same as that of Worthington pumps, and the steam valves of one side are operated from the piston rod of the other side. Steam is carried full stroke in all cylinders.

77. Triple Expansion Center-Packed Pump.—Fig. 31 is a side view of one side of a triple-expansion duplex Worthington mine pump having plungers which are center-packed.

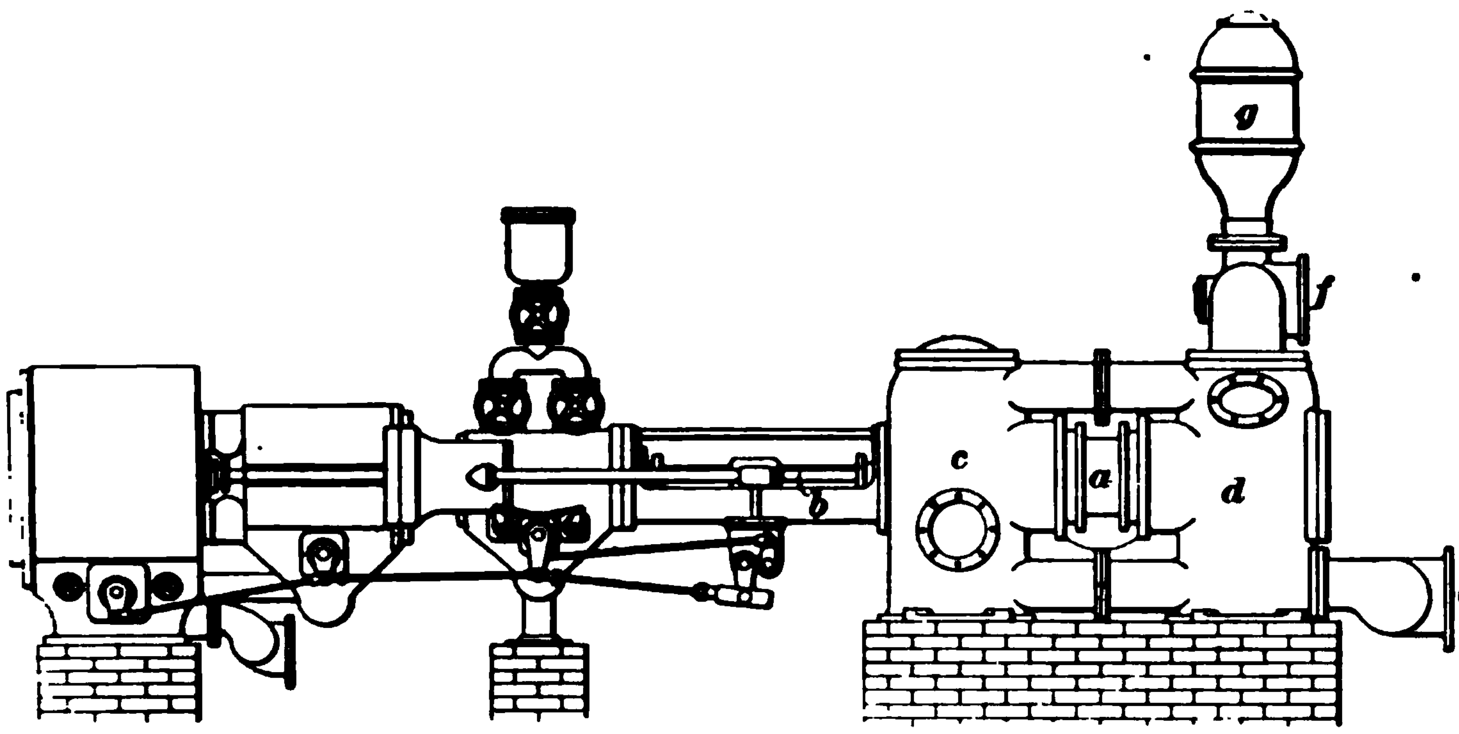


FIG. 31.

The type of water end used with this pump has been given the name of **Scranton type** by the makers. Sectional views of the steam cylinders of this pump have already been given in Figs. 9 and 10. The plunger *a* is connected to the piston rod *b* and works in the pump chambers *c* and *d*, which have the suction valves on the bottom and the delivery valves on top. The suction pipe is connected at *e* and the delivery valve at *f*. An air chamber *g* on the delivery absorbs shocks and promotes a steady delivery. The pump is double-acting.

FLYWHEEL PUMP.

78. Fig. 32 (*a*) is a side view of the high-pressure side of a duplex pump driven by a cross-compound Corliss engine, the pump being of the double-plunger type. Fig. 32 (*b*) is an end view of the water end of both pumps, looking towards the engine, and Fig. 32 (*c*) is an end view of the engine, looking towards the flywheel, the observer being supposed to stand between the pumps and the engine. The plungers *a* and *b* are connected by yokes *c*, *c* and rods *d*, *d* and are driven

directly by the piston rods of the high-pressure and low-pressure cylinders, which for this purpose are prolonged beyond the pistons and pass through the back cylinder heads.

79. The pump cylinders have the necessary diaphragm *e* in the center, and each pump cylinder has two valve chambers *f*, *f'* containing the suction valves and two valve chambers *g*, *g'* containing the delivery valves. These valve chambers are placed on both sides of the pump cylinders. The four suction-valve chambers of each pump connect to the common suction branch *h*, and the two branches in turn are connected to the suction main by a **Y** fitting not shown in the illustration. The four delivery chambers of each pump are connected together by branch pipes, and these branch pipes in turn discharge into a common main delivery pipe.

80. A reheating receiver *i* is placed between the high-pressure and low-pressure cylinders. The low-pressure steam inlet valves are placed beneath the low-pressure cylinder; the low-pressure exhaust valves are on top and exhaust directly into the condenser *k*, which is placed on top of the low-pressure cylinder. The high-pressure valves are arranged in the usual way. The engine is provided with a variable speed Porter governor *l*, by means of which the speed of the engine may be varied to suit the requirements of the service.

81. The particular pump illustrated has cylinders nches and 60 inches in diameter and a 48-inch stroke, the gers being 13¾ inches diameter. It was designed by Dickson Manufacturing Company, of Scranton, Pennsyl-, to pump water highly charged with sulphuric acid st a head of 700 feet. To guard against corrosion, the cylinders, valve chambers, and all pipes were lined lead and the plungers and valves made of acid-resisting nposition. Owing to the high economy possible through e use of a compound condensing Corliss engine, this is ntly called a "high-duty mine pump" by the builders.

DISPLACEMENT PUMPS.

DEFINITION AND CLASSIFICATION.

82. **A displacement pump** is a pump in which there is a complete absence of moving parts and where the fluid to be pumped is moved by steam or compressed air. Of the steam-operated displacement pumps, the best known is the *pulsometer;* the *Harris compressed-air direct-air-pressure pump* and the *Pohlé air lift* are the best known air-operated displacement pumps.

THE PULSOMETER.

83. Fig. 33 shows a perspective view and Fig. 34 a sectional view of a pulsometer of the latest manufacture. In the sectional view the full lines represent the left-hand half and the dotted lines indicate the position of the discharge valves in the right-hand half of the pulsometer shown in Fig. 33. In the following description, the letters refer to both figures: The steam pipe is connected at *E* and the suction pipe at *S*. *C* is an air chamber that has no connection with *B* and *A*, but communicates with the suction pipe by means of the opening *I* situated below the suction valves *F* and *G*. The two latter valves are made of flat rubber and are held to their seats, as shown in the figure, by means of the spindles *R* and *T*. The spindles are raised and lowered, as the case may require, by means of the bolts *f* and *e*. *H*, *H* are plates that may be removed to facilitate the examination of the valves. *D* is a hard-rubber ball that acts as a valve for admitting the steam to the chambers *A* and *B*. *M* and *N* are exhaust valves, also made of rubber and situated in the chamber *L* attached to the other half of the cylinder. They are raised and lowered in the same manner as the suction valves by turning the bolts *g* and *h*. *K* is the delivery or column pipe.

84. The action of the pulsometer is as follows: Both chambers A and B are filled with water to about the height of the water in B, Fig. 34. The valve d is then opened and the steam enters one of the two chambers A and B. Sup-

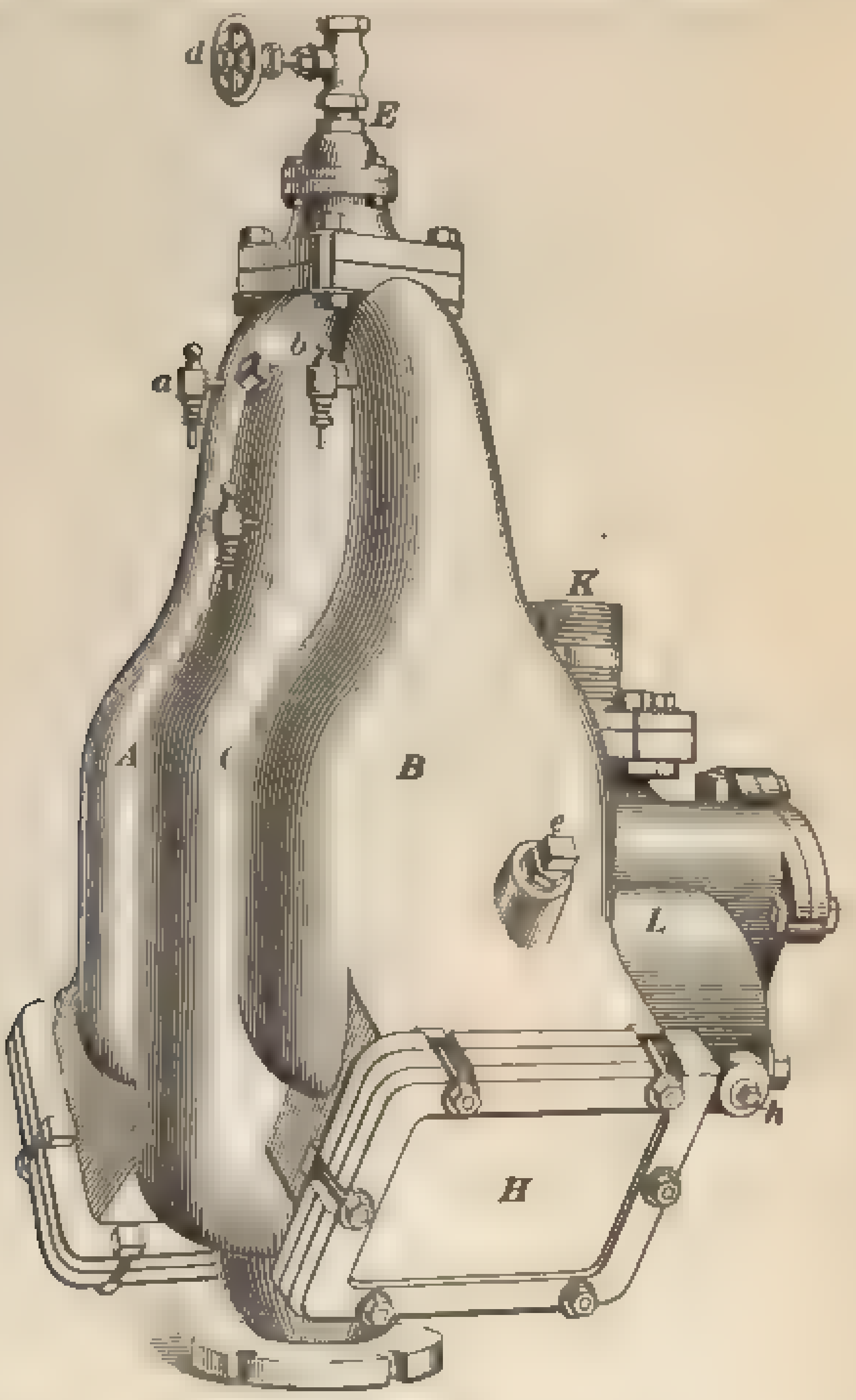


FIG. 33

pose it enters B, the valve D being at the right, as shown. The water in B will be forced through the delivery valve N into and up the column pipe K. This will continue until the water level gets below the edge of the discharge

opening *P*. At this point the steam and water mix in the discharge passage and the steam is condensed, creating a vacuum in *B*. The pressure in *A* is now greater than that in *B*, owing to the vacuum in *B*, and the ball valve *D* is shifted to the left, the steam entering the chamber *A* and

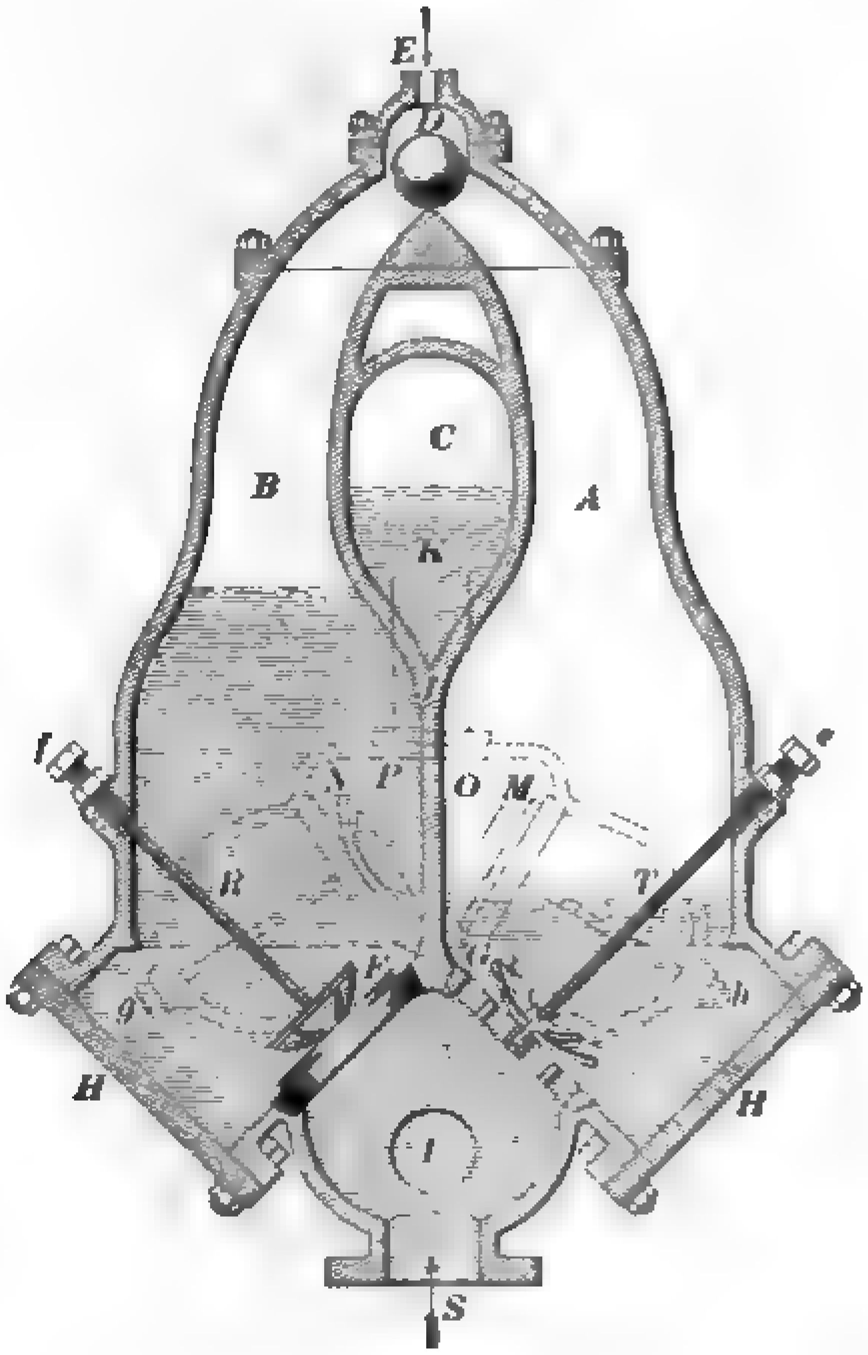


FIG. 34

driving the water through *M* into the passage *O* and column pipe *K* in the manner just described. While this is being done, the pressure of the atmosphere forces the water up the suction pipe *S*, opening the suction valve *F*, and into

the chamber B, filling it. When the suction valve is closed, owing to the reshifting of the ball valve D to the other side, the suction water enters the air chamber C through the inlet I and is brought gradually to rest by the compression of the air in C, thus preventing a shock owing to the sudden stoppage of the inflowing water. When the water in A has reached the level shown, the steam in A is condensed, the ball D is shifted to the right, and B becomes the driving chamber.

85. In Fig. 33 are shown three small air valves a, b, and c. The valve c admits air to the air chamber C, to replenish that which is lost through leakage and through absorption by the water. The valves a and b admit a small quantity of air to the chambers A and B, respectively, just before the suction begins. This injures the suction somewhat, but is necessary for two reasons. First, it acts as a regulator, governing the amount of water admitted to the chambers; and second, it prevents the steam from condensing before the water gets below the edge of the discharge outlet. These valves open inwards, as before stated. Suppose there is a vacuum in A owing to the condensation of the steam. The atmospheric pressure forces open the valve a and admits a little air to the cylinder. The incoming water compresses this air and soon closes the valve. When the air has been compressed to such an extent as to [illegible] the atmosphere, the suction [illegible] get in. Since the [illegible] it is evident that [illegible] the amount of water [illegible] water entering [illegible] and vice versa. The [illegible] the valves a [illegible] the suction valve [illegible] the ball is shifted [illegible] from coming in con- [illegible] until the

water level has sunk below the edge of the discharge orifice. Air being a poor conductor of heat, the steam does not condense until the mixture of the steam and water has taken place.

86. When the barometer stands at 30 inches, the pulsometer will raise water by suction to a height of about 26 feet, although it is not advisable to exceed 20 feet, and force it, when necessary, to a height of 100 feet. It has no wearing parts whatever except the valves, which are easily and cheaply repaired. It will work in almost any position, and when once started requires no further attention. There are no parts that can get out of order. It will pump anything, including mud, gravel, etc., that can get past the valves. Its first cost is low and it requires no foundations to set up. There is no exhaust steam to make trouble and no noise.

THE DIRECT-AIR-PRESSURE PUMP.

87. The direct-air-pressure pump here shown is the design of Professor Elmo G. Harris and is one of the simplest forms of pump. The pump is shown in diagrammatic form in Fig. 35. There are two pump tanks *a* and *b*, which are fitted with suction valves *c* and *d* and discharge valves *e* and *f*. The two tanks are connected to the common suction pipe *g* and both discharge into the same discharge pipe *h*. The tops of the pump tanks are connected by pipes *i* and *k* to an air compressor *m*, and by means of an automatically operated four-way cock *l*, either tank can be connected to the compressor side of the air compressor. The operation is as follows: with the cock *l* in the position shown, the tank *b* is connected to the suction side of the air compressor, and hence a vacuum is formed in the tank *b*. Consequently, the water in the supply is forced by atmospheric pressure up the suction pipe *g*, lifts the valve *d*, and passes into the tank *b*. At the same time the tank *a* is connected to the compressor side, and the air pressure on top of the water forces it out, the water holding the suction valve *c*

closed but opening the delivery valve c and passing up the discharge pipe h. When the tank a is nearly empty, the tank b

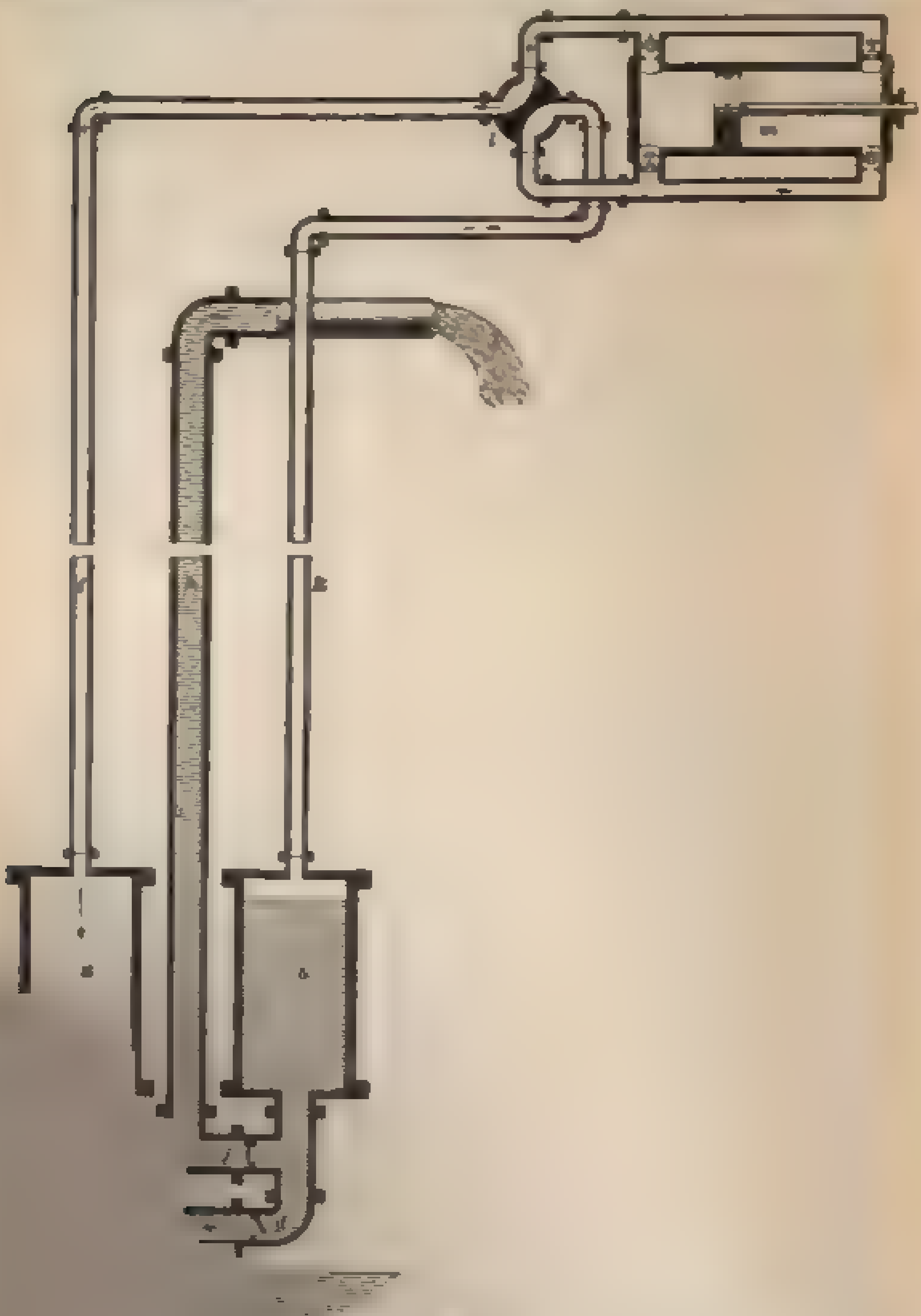


FIG. 35

; the cock l is then turned automatically so as tank in communication with the suction side

of the air compressor and the tank *b* in communication with the compressor side. The water now flows into *a* and out of *b*, and the cycle of operations is repeated as long as the air compressor is working. The height to which water can be forced obviously depends on the pressure to which the air is compressed.

THE POHLÉ AIR LIFT.

88. The Pohlé air lift is much used for pumping water from artesian wells; it is operated by means of compressed air and has no moving parts. It is not affected by sand or

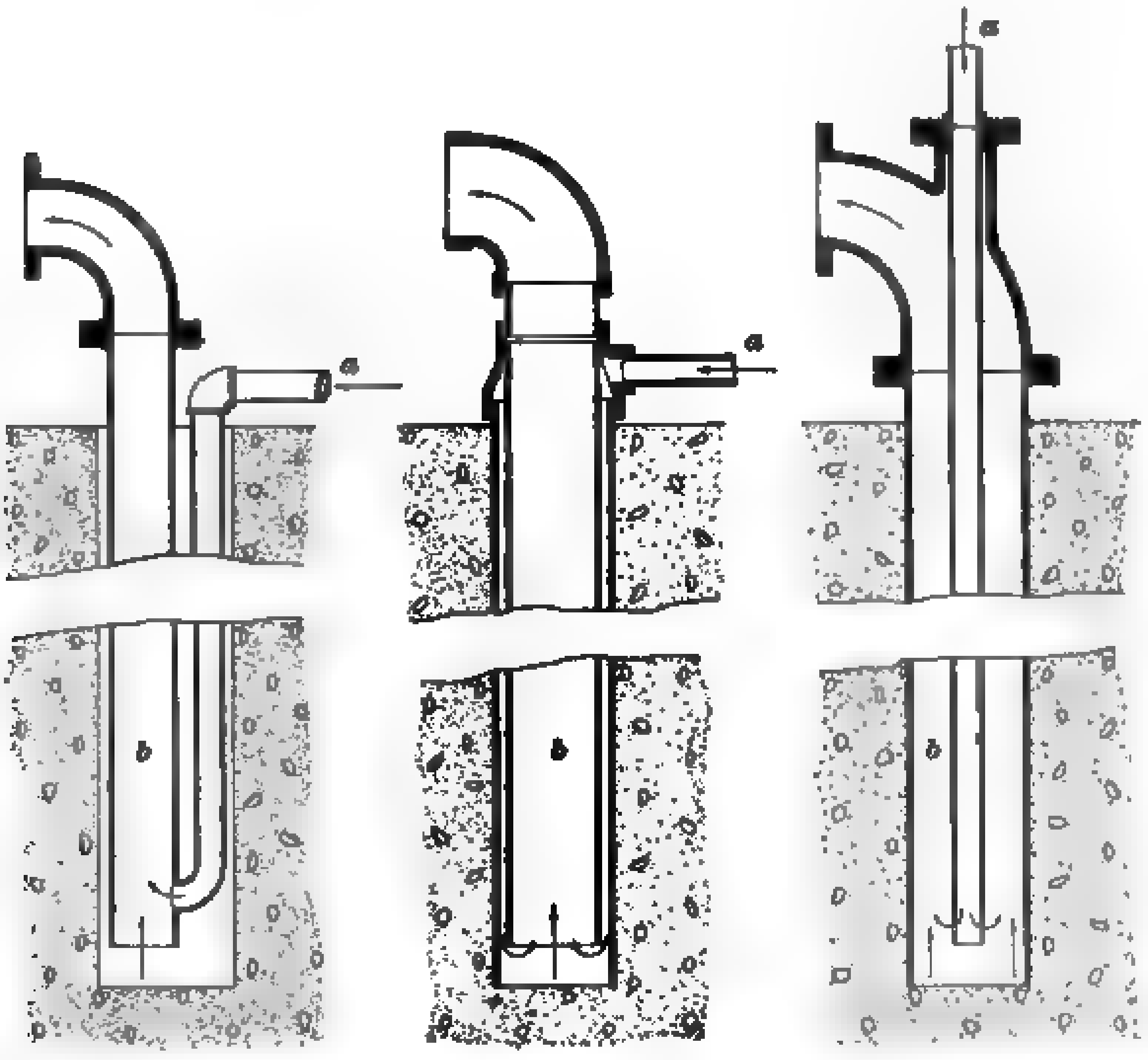


FIG. 36.

grit and the water is benefited to a considerable extent by the action of the air, in that it purifies and cools the water while it is being pumped. Other advantages claimed for

this device is that it increases the yield of an artesian well from two to five times; also, the full area of the well is available for a flow of water. Compressed air is supplied by means of an air compressor at the surface, which may be located in any convenient position, or one air compressor may supply several artesian wells.

89. The operation of the pump is as follows: Two properly proportioned pipes are inserted in the well, using either of the three arrangements shown in Fig. 36. Compressed air is supplied through the pipe *a* to the bottom of the well tube *b*. At the beginning of the operation the water inside and outside of the pipe is at the same level. When air is forced in through the pipe *a*, it forms alternate layers with the water, so that the pressure per square inch of the column thus made up of air and water inside of the water pipe is less than the pressure per square inch outside the pipe. This difference of pressure causes a continuous flow from the outside to the inside of the water pipe, and its ascent is constant and is free from shock or noise of any kind. The strata of compressed air in their ascent prevent any slipping back of water. As each stratum progresses upwards to the spout, it expands on its way in proportion to the overlying weight of water, so that the pressure of the air gradually becomes less and finally reaches the atmospheric pressure.

WATER ENDS OF RECIPROCATING PUMPS.

TYPES OF WATER ENDS.

90. Reciprocating pumps are either single-acting or double-acting. Single-acting pumps are either lift pumps, one of which is shown in Fig. 25, or outside-packed plunger pumps with one plunger, as shown in Fig. 26, or outside-packed double-plunger pumps, as shown in Figs. 29, 30, and 32. Double-acting pumps are force pumps of the piston

or plunger pattern. Piston pumps, by reason of their construction, are inside-packed, and such a pump is shown in Fig. 6. Double-acting plunger pumps are inside-packed or center-packed. Attention is here called to the fact that outside-packed double-plunger pumps are often, but erroneously, considered as double acting. While they give a discharge equal to that of a double-acting plunger pump, it is obtained by combining two single-acting plunger pumps to discharge into the same delivery pipe, and hence it is incorrect to call such a pump a double-acting pump. They are properly called **duplex pumps.**

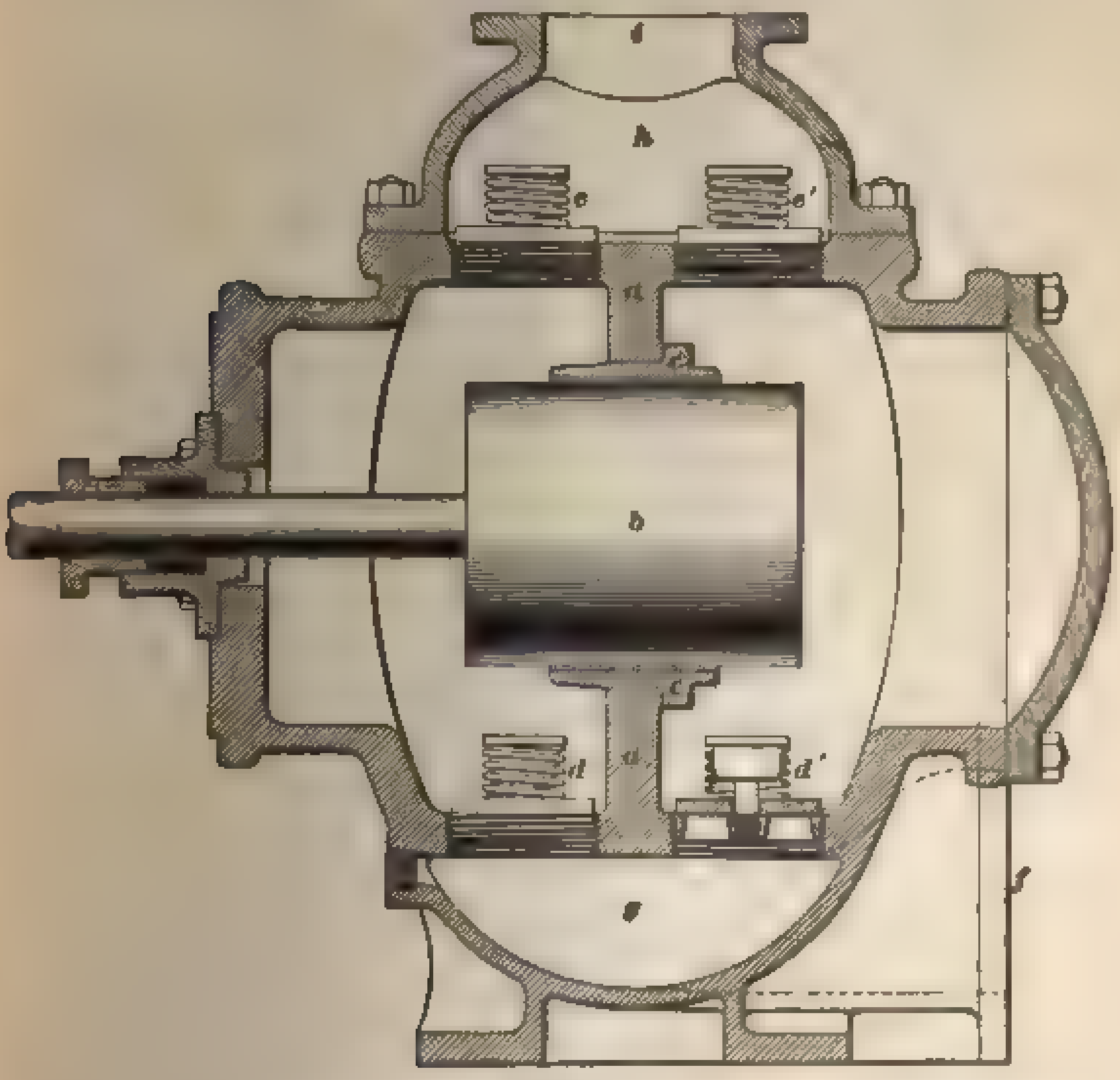


FIG. 37.

91. Fig. 37 shows the water end of a **double-acting inside-packed plunger pump.** The pump chamber is divided into two parts by a partition a, through which the

plunger b works back and forth. A water-tight joint between the plunger and partition is made either by a closely fitting

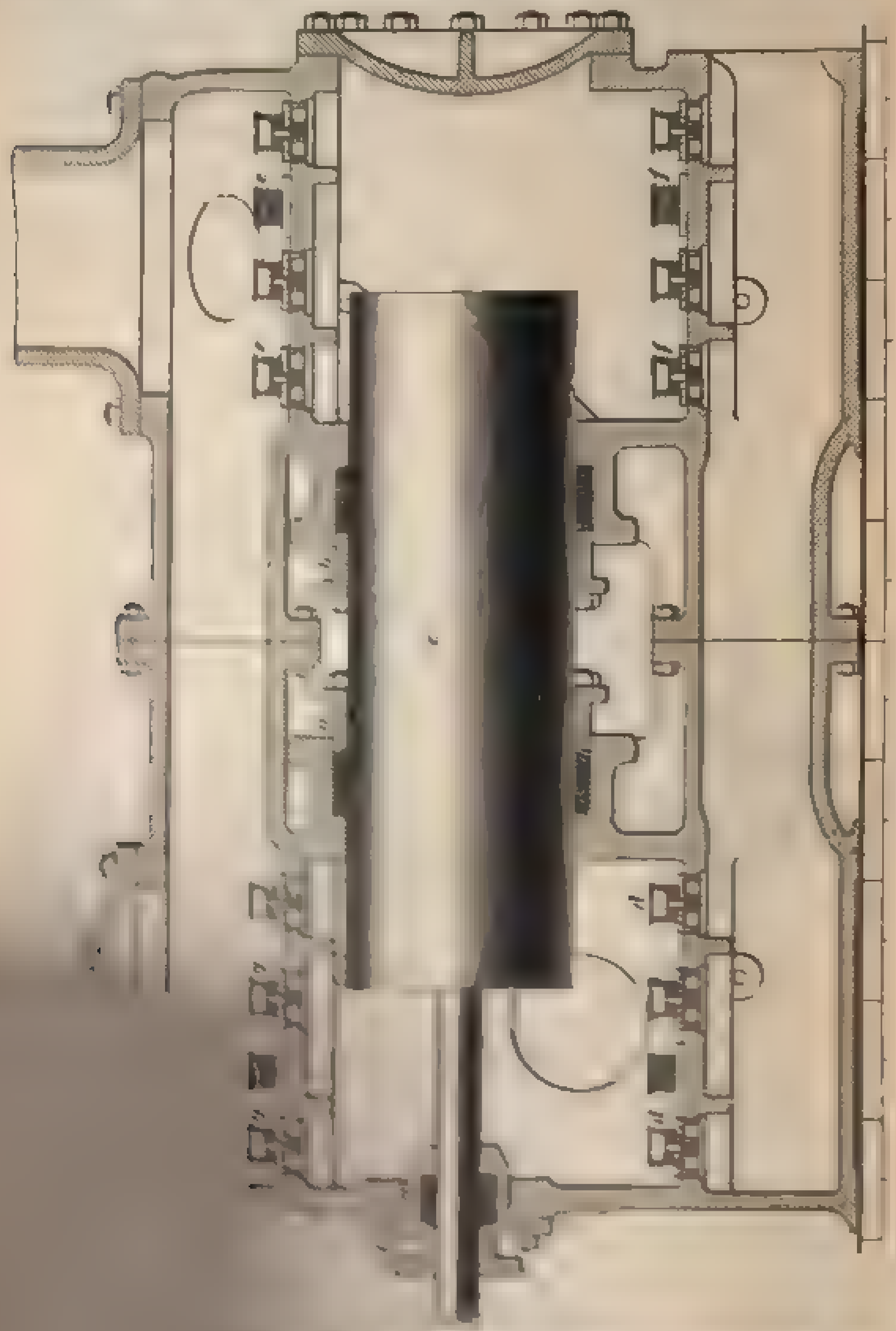


FIG. 38.

[illegible] and gland [illegible] partition is a set

of suction valves *d*, *d'* and delivery valves *e*, *e'*. The water enters the pump through the suction pipe, which is connected at *f* and flows into the suction-valve chamber *g*, from whence it passes to either side of the partition *a* and then into the delivery-valve chamber *h* and into the delivery pipe connected at *i*. When the plunger moves to the right, it displaces the water on the right of the partition *a*; the suction valve *d'* is closed by the pressure existing there, while the delivery valve *e'* is open and the water discharges into *h*. At the same time the plunger creates a partial vacuum at the left of the partition *a* and, hence, water flows through the open suction valve *d* into the left pump chamber. The delivery valve *e* is kept closed by the pressure in *h*. When the plunger moves to the left, the suction valve *d'* and delivery valve *e* open and the suction valve *d* and delivery valve *e'* close. It is thus seen that the pump discharges during either stroke of the plunger, i. e., the pump is double-acting.

92. Fig. 38 shows a sectional view of the water end of a center-packed double-acting plunger pump, the stuffing-boxes *a* and *b* being used for packing the plunger *c*. The action of the pump is identical with that of the pump shown in Fig. 37, that is, when the plunger moves to the right the suction valves *d*, *d* and delivery valves *e*, *e* are open and the suction valves *f*, *f* and delivery valves *g*, *g* are closed. When the plunger moves to the left, the suction valves *f*, *f* and delivery valves *g*, *g* are open and the suction valves *d*, *d* and delivery valves *e*, *e* are closed.

93. The water end of a double-plunger pump for high pressures is shown in Fig. 39. The two plungers *a*, *b*, as usual, are connected by yokes and side rods outside of the pump. The rods *i*, *i* tie the water end to the steam end. Each plunger has its own suction valve *e* and delivery valve *f*. The suction valves communicate with a common suction chamber, to which the suction pipe *c* is attached. At *d* the discharge pipe is shown. Plugs *g*, *g* when removed give access to the valves. A standard *h* supports the water end

on its foundation. The illustration clearly shows that each plunger is single-acting, but that the discharge is equal to that of a double-acting pump. Pressure pumps do not differ

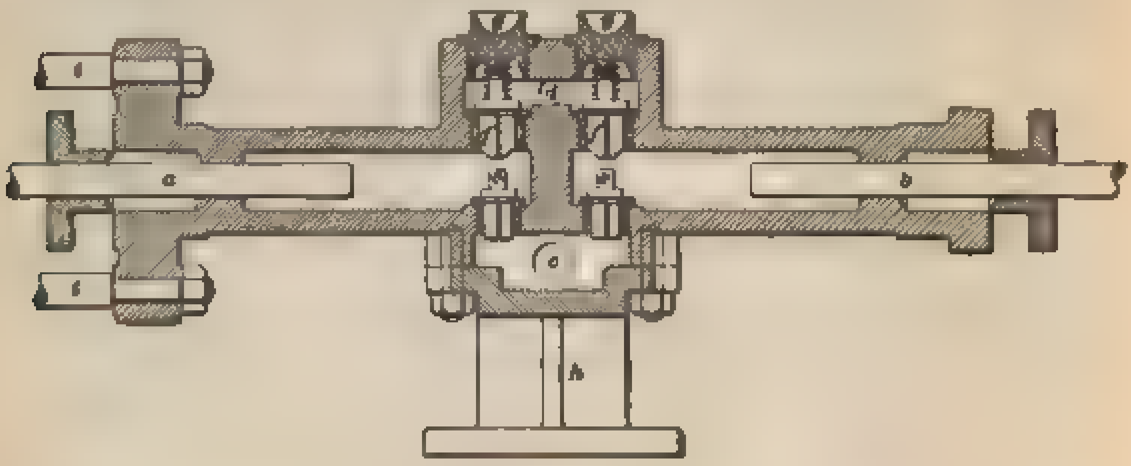


FIG. 39.

in their operation from ordinary pumps; all parts are simply made extra heavy so as to stand the high pressure, and for very high pressures steel is substituted for cast iron in the water end.

94. Fig. 40 shows in diagrammatic form two forms of a plunger pump that is double-acting and is known as a **differential pump.** Its distinguishing feature is that it needs only one set of suction valves and delivery valves. Fig. 40 (*a*) shows the arrangement used for two plungers *a* and *b*, which are connected together by yokes and side rods. In Fig. 40 (*b*), the two plungers are connected directly together. In both designs one plunger, as *a*, has exactly double the area of the other plunger *b*. This fact must be carefully borne in mind. Since the stroke of both plungers is the same, it follows that the larger plunger in Fig. 40 (*a*) will displace double the quantity of water that the smaller plunger displaces. In Fig. 40 (*b*), the left hand side of the plunger *a* displaces double the quantity of water displaced by the plunger *b*. In both designs *c* is the suction valve and *d* the delivery valve.

95. The operation of the differential pump shown in Fig. 40 (*a*) is as follows: The pump being filled with water and the plungers moving to the right, the suction valve is

open and the delivery valve closed. The plunger *b*, or the right hand side of the plunger *a* in Fig. 40 (*b*), forces a volume of water equal to its displacement out of the chamber *e* and up the delivery pipe *f*. At the same time, double the volume of water is drawn into the suction chamber *h*.

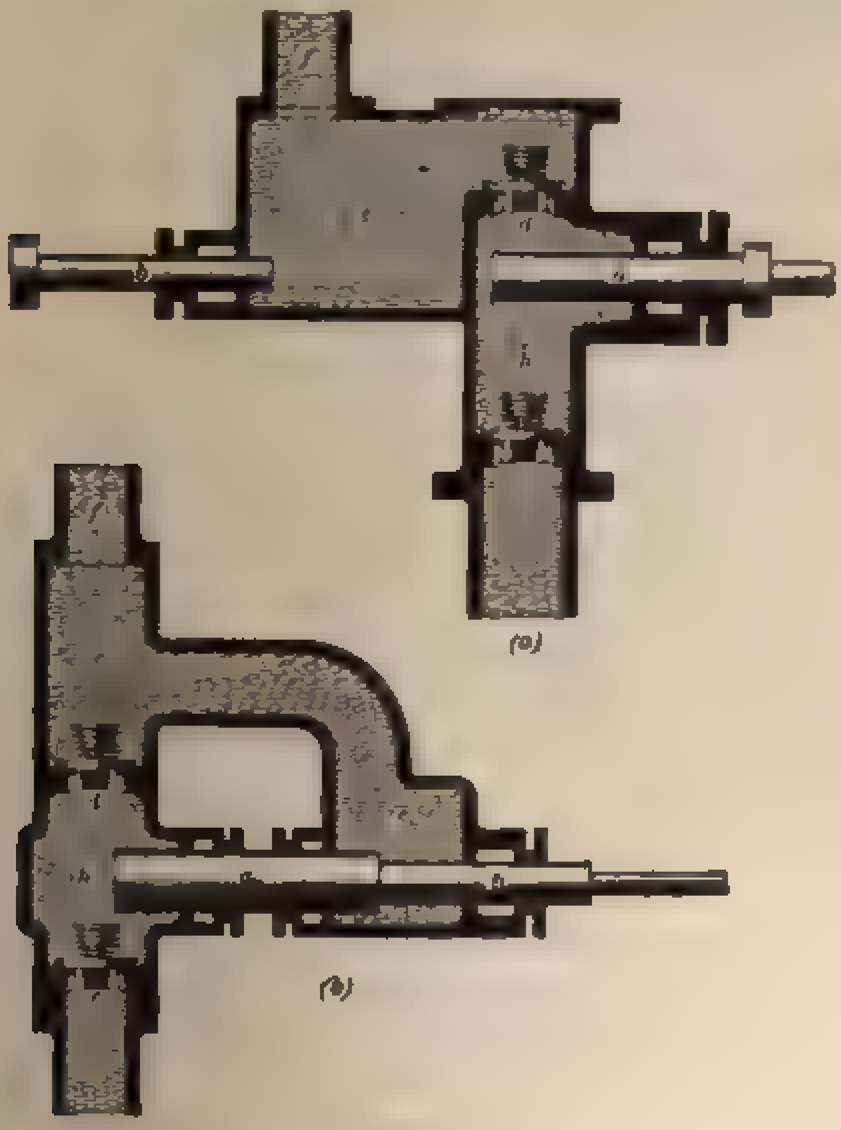


FIG. 40.

Now, assume that the plungers move to the left. The suction valve is then closed and the delivery valve is open, and double the quantity of water discharged during the stroke to the right now flows into the chamber *e*. But while this is going on, the volume of the chamber *e* increases by the receding of the plunger *b*, or the outward movement of the plunger *a* in Fig. 40 (*b*), by an amount that at the end of the stroke is equal to exactly one-half the amount discharged into it, so that the outflow into the delivery pipe is

only one-half of that discharged into the chamber *c*. This outflow is equal to the displacement of the small plunger, or the right-hand end of the plunger *a* in Fig. 40 (*b*), and hence the same amount of water is discharged during both strokes.

RIEDLER PUMPS.

96. Development.—Riedler pumps are the invention of Professor Riedler and are a type of pump designed for running at very high speeds. By study, experimenting, and careful noting of cause and effect, he discovered several very important phenomena. He found that there was much greater resistance to the flow of water through the valve passages and ordinary pumps than was before this thought to exist. He further found that the slip of ordinary valves is very large, and that even when small has a great tendency to cause severe hydraulic shocks throughout the pressure parts of the pump He also was aware that the frictional resistance to the passage of a certain quantity of water through a large number of small openings is much greater than that existing when the same quantity of water passes through a single opening equal to the combined area of the smaller ones. With these facts in view, Professor Riedler designed a pump valve having the useful valve area as large as possible and containing as few separate passages as is consistent with good construction. He substituted one large valve for many small ones, thus decreasing the friction of the water in the valve passages. The reduction of the slip was accomplished by arranging a mechanical controlling device, whereby at the proper time and without restricting the water passage the valve was closed. The mechanical controlling device further assists in the reduction of friction in the valve passages, as it permits the valve lift to be high, thus increasing the effective area

97. The first pumps fitted with Riedler valves were constructed in 1884, since which time more than 1,500 pumps have been built. These pumps are adapted to any service

to which pumping machinery may be applied. They are built in all sizes, ranging in capacity from 115,000 gallons in 24 hours to 20,000,000 gallons in 24 hours, and are working under heads as high as 2,480 feet and at speeds as high as 120 revolutions per minute, and with piston speeds as high as 606 feet per minute, which, by the way, is the average speed of steam pistons.

98. Valve Gear.—Fig. 41 shows an outside view of a direct-connected electrically driven differential Riedler pump having the plunger arrangement shown in Fig. 40 (*b*). The pump valves are closed by cranks, the crank *a* operating the suction valve and the crank *b* the delivery valve. The two cranks are operated from a wristplate *c* similar to that of a Corliss engine and to which they are connected by the rods shown. The wristplate is rocked back and forth by the eccentric *d* on the crank-shaft, to which it is connected by the eccentric rod *e*. The plungers are driven by a crank, as shown.

99. Riedler Valve.—Fig. 42 shows a detail of the improved Riedler suction and delivery valve. Both suction and delivery valves are alike in these pumps except as regards the flange for securing them to the pump chambers. The valve proper consists of three concentric bronze rings *a*, *b*, and *c*, each of which is cast in one piece and which are set into a spider *d* having eight arms. This spider is free to move up and down on the central valve post, or valve spindle *e*. This valve rests on a heavy cast-steel valve seat *f* having three annular openings *a'*, *b'*, and *c'*. The valves proper are not rigidly connected to the spider, but each valve is free to form its seat with the valve seat and independent of the spider or each other. A leather ring between the valve proper and the spider serves to make an absolutely tight joint. A circular nut *g* is secured to the top of the hub of the valve spider *d* and holds in place a steel pressure plate *h*. This pressure plate rests on top of a spring cap *i*, below which a spring *k* of soft rubber is placed. This rubber allows of a certain amount of yield between the valves

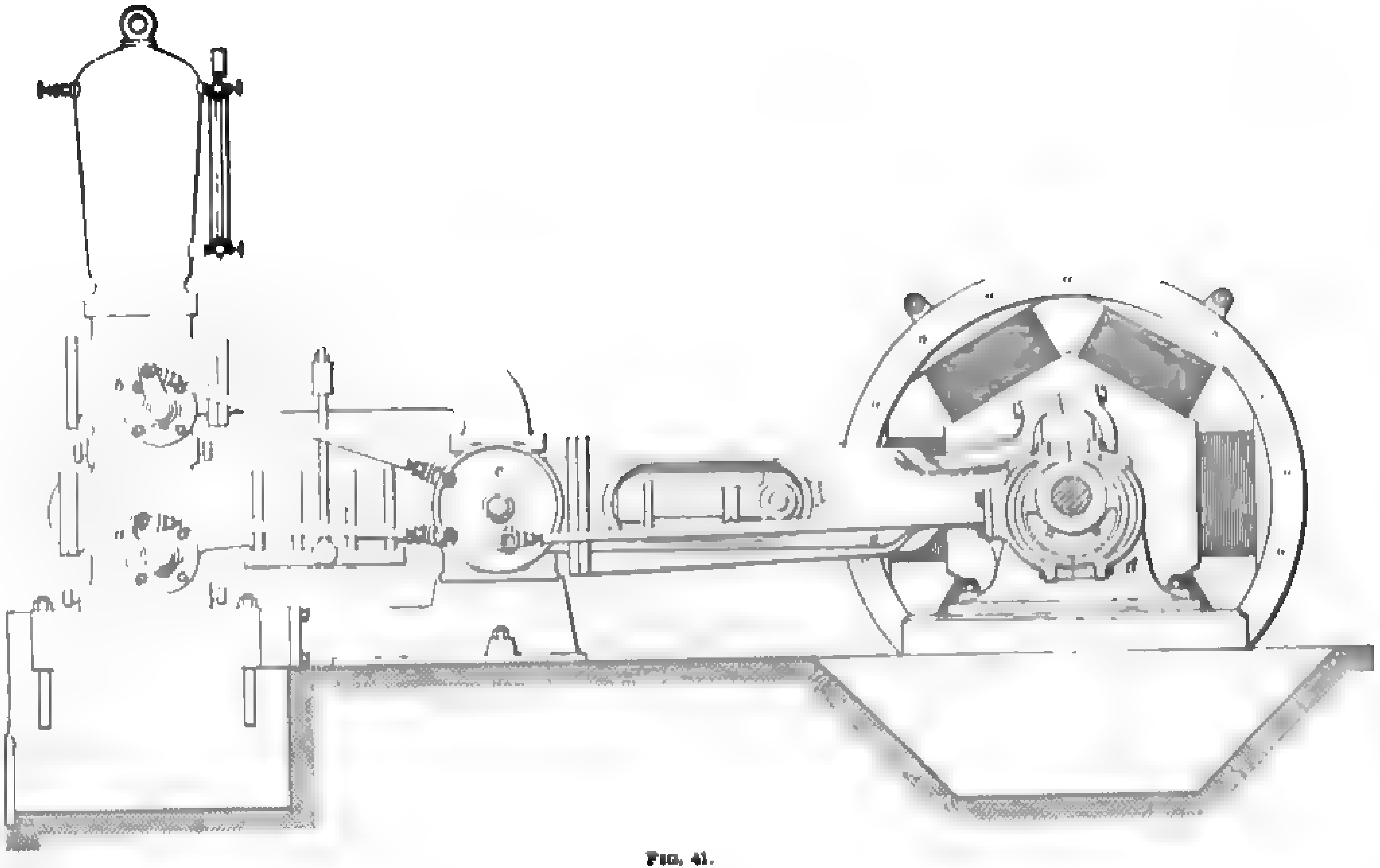


FIG. 41.

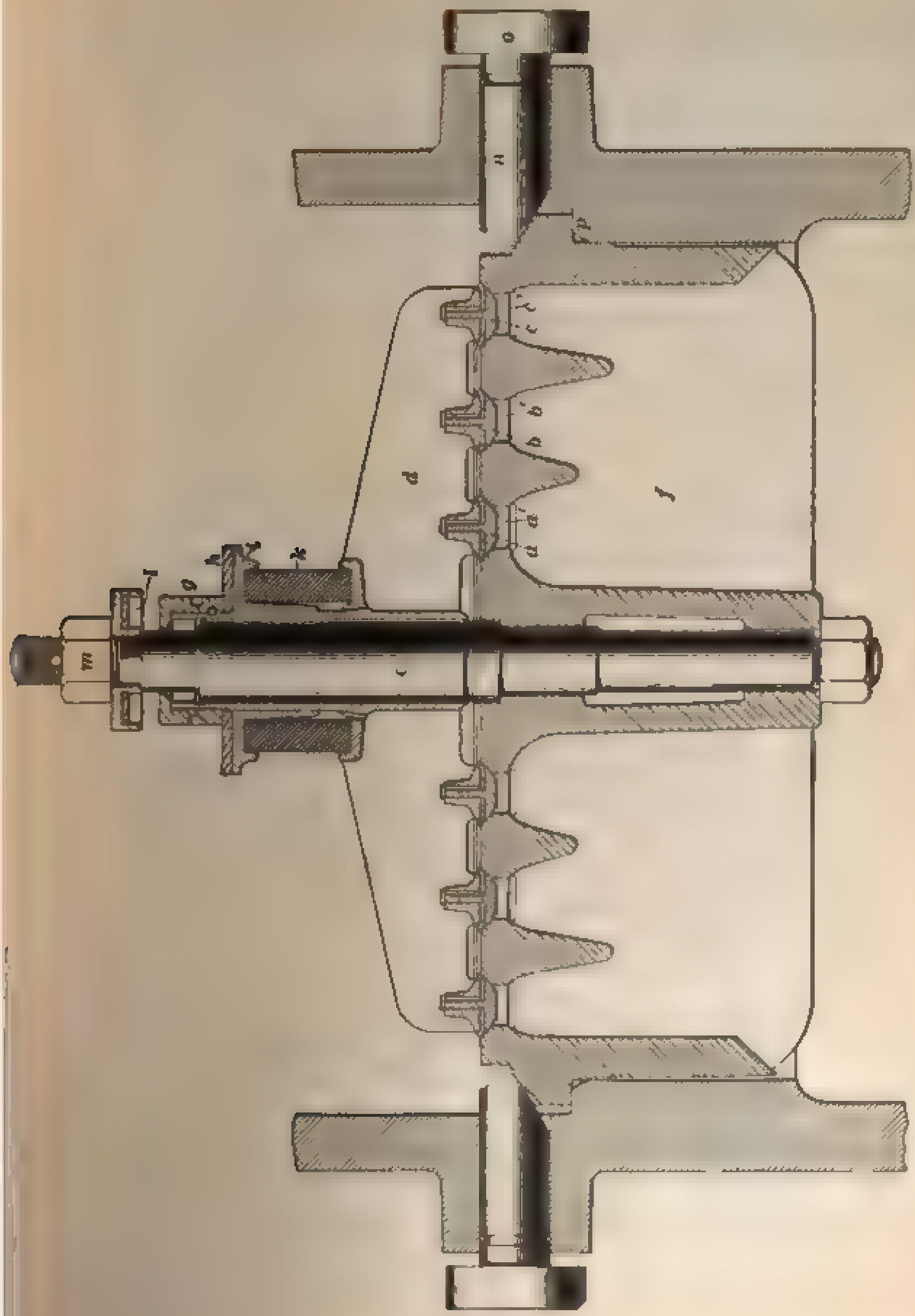


Fig. 42

and its seat in case any foreign matter should get between them. Two steel fingers, not shown in the drawing, press upon the pressure plate and serve to close the valve just before the piston reaches the end of its stroke. A water cushion [illegible], the object of which is to prevent the valve from striking its stop when opening, is secured to the top of the spindle [illegible] by the nut [illegible]. The nut [illegible] is loosely fitted to the chamber in *l* and traps the water in front of it, thus making a hydraulic cushion. The valve seats are secured in the valve chambers by wedge-shaped pieces [illegible], which are forced in by studs and nuts through the glands, the effect being to force the valve seat [illegible] hard down on its bearing *p* in the pump chamber.

100. Fig. 43 is a perspective view of the Riedler valve and seat, showing the operating mechanism by means of which the valve is seated. All visible parts are lettered the

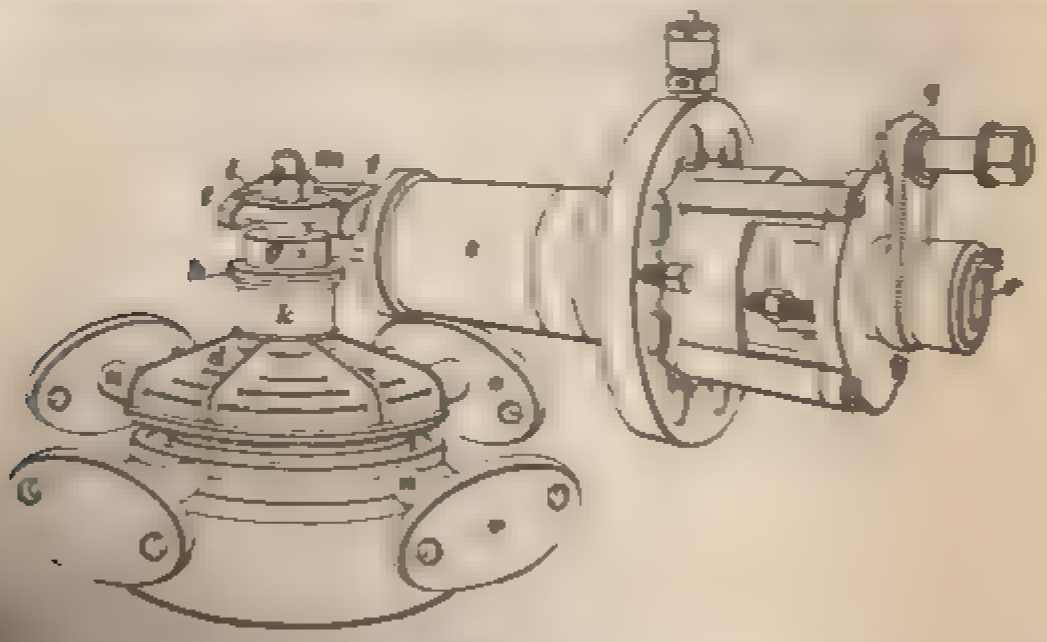


Fig. 43

[illegible] as in Fig. 42. The crank *q* is operated from the [illegible] shown in Fig. 41; it is keyed to a shaft *r*, which [illegible] through a stuffingbox *s* bolted to the valve chamber [illegible] a forked crank at its inner end. The jaws or [illegible] *t*, *t* of the forked crank press upon the pressure [illegible] to seat the valve at the proper time. The motion of [illegible] is so timed in relation to the motion of the

plungers that the fingers are clear of the pressure plate *h* when the plungers begin to deliver water, thus leaving the valve free to open.

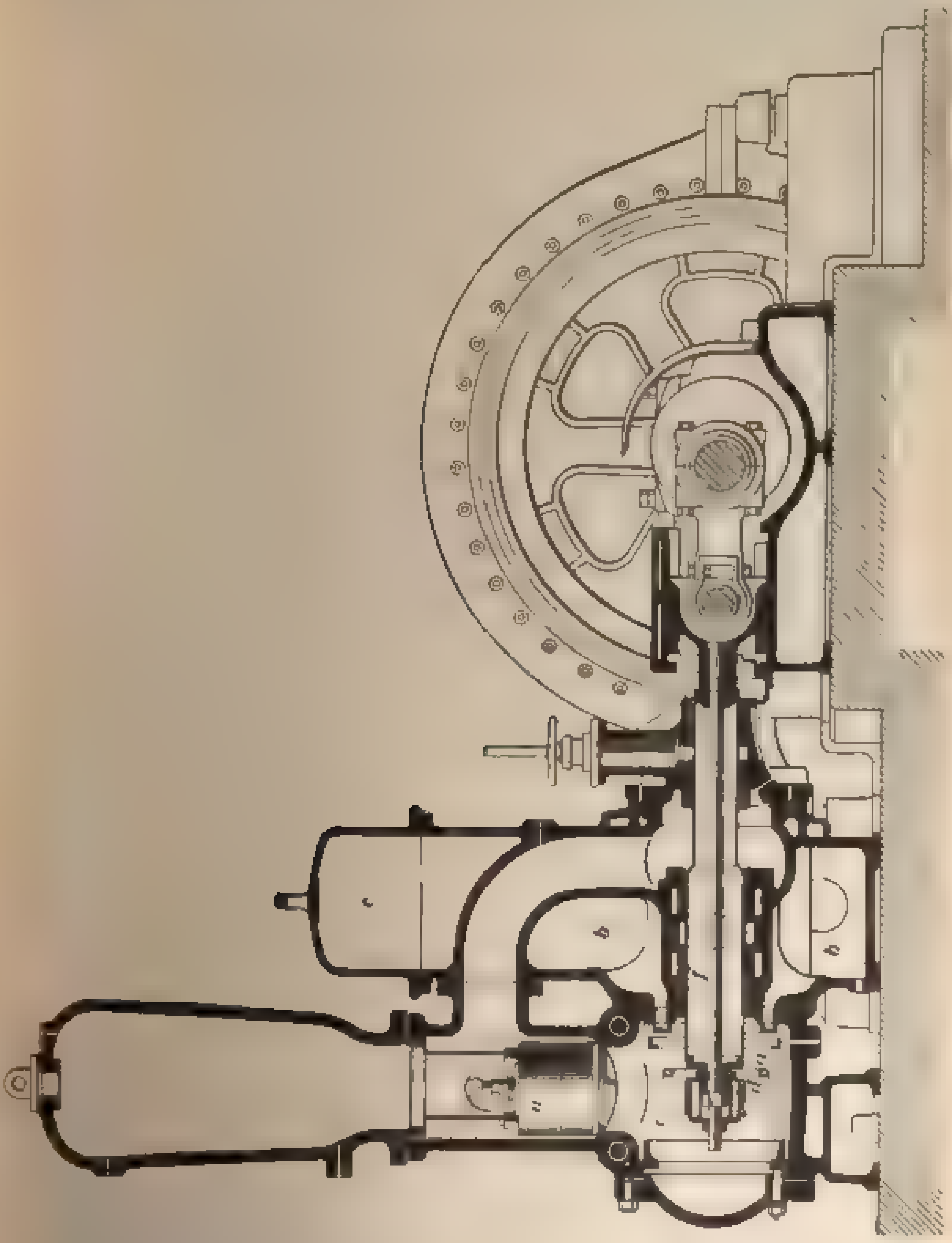


FIG. 44.

101. The Riedler valve is by no means confined only to water pumps. It has been and is used successfully for high pressure air and gas compressors. The Riedler pump may

be driven by a steam engine, electric motor, turbine, waterwheel, by belting, or in any other convenient manner.

102. Riedler Express Pump.—A type of Riedler pump that has recently been brought out for running at a very high speed is called the **Riedler express pump** and is shown in Fig. 44. Although the ordinary Riedler pump can be run at speeds as high as 150 revolutions per minute and sometimes faster, conditions arise requiring a much higher speed, and to meet this condition this special design, which may be run at speeds as high as 400 revolutions per minute, has been developed by Professor Riedler. The main feature of this pump, in fact, the part that permits running at such high speeds, is its suction valve. As will be seen by referring to the figure, the suction valve *a* is annular in form and is concentric with the plunger; it lifts in the direction opposite to that of the plunger when on its suction stroke, the water flowing from the suction chamber *b* into the valve chamber *c*. At the end of the suction stroke a buffer *f* mounted upon the end of the plunger drives the suction valve to its seat, making it certain that the valve is seated when the plunger starts on its delivery stroke and allowing practically no slip. A high suction air chamber *e*, containing a column of water, is placed above the suction valve, making it certain that the pump will fill as the plunger *e* makes its suction stroke. The delivery valve is shown at *g*. It will be noticed that this pump is of the differential type.

103. The chief point of advantage of the express pump is that it may be connected to high-speed motors. It is of small dimensions compared to the quantity of water it can handle, and thus consequently low in first cost. About fifty of these pumps have been constructed up to the year 1901, ranging in capacity from 150,000 gallons in 24 hours to 7,000,000 gallons in 24 hours, and in speed as high as 300 revolutions per minute, pumping against a head [illegible] have been built to pump against a head of 800 feet at 200 revolutions per minute.

PUMPS.

(PART 2.)

DETAILS OF PUMP WATER ENDS.

PUMP PLUNGERS.

CONSTRUCTION.

1. The smaller sizes of pump plungers are usually made of solid round bars of metal turned smooth, so as to work through a stuffingbox with as little friction and wear as possible. Fór larger sizes the plungers are frequently of cast iron and are often made hollow to reduce the weight and amount of material required. Incidentally, it may be remarked that a hollow plunger is easier to move than a solid one, all other conditions being equal. This is due to the fact that the water buoys up a hollow plunger more than a solid one. In large horizontal pumps hollow plungers are often so proportioned that they actually float in the water, thus relieving the stuffingboxes of the weight of the plungers and reducing the wear.

2. Fig. 1 shows a simple form of solid plunger pump, such as is often used for feeding boilers. The plunger works through a stuffingbox of the ordinary pattern, packed with hemp or some of the common types of soft piston-rod packing.

3. Fig. 2 shows three styles of large, hollow, cast-iron

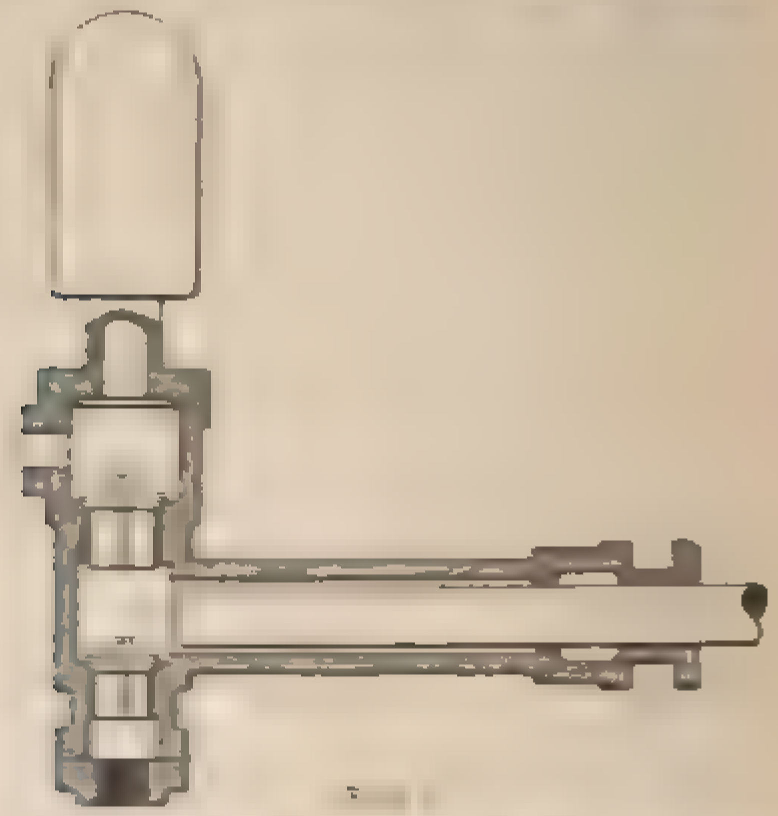


FIG. 1

plungers with methods of attaching them to the pump rods. The packing for these plungers, when used for moderate pressures, is usually hemp contained in a stuffingbox of the ordinary pattern.

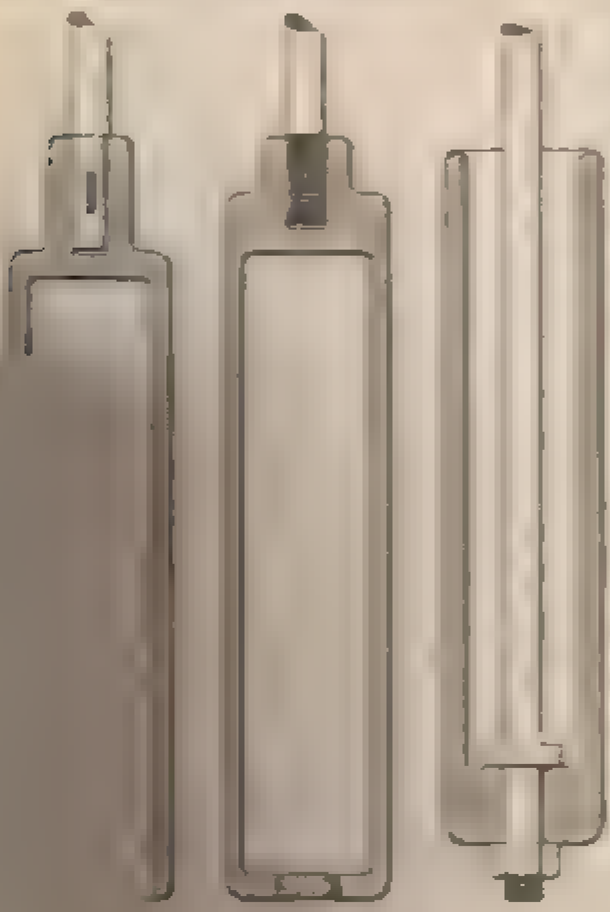


FIG. 2

PLUNGER PACKING.

4. When the pressure under which the pump works is very heavy, U-shaped leather packing is sometimes used. Fig. 3 shows three methods of holding these **cup leathers**, as they are called. The section at (a) shows the leather held in a recess cast in the upper end of the

pump cylinder. In this case it is necessary to remove the plunger D in order to insert a new leather or to examine an old one. Experience also shows that the leather bears against the plunger with the greatest force at the bend B and fails at that point first. In (c) the leather is held in its recess by a gland s, and is also supported by a brass ring C,

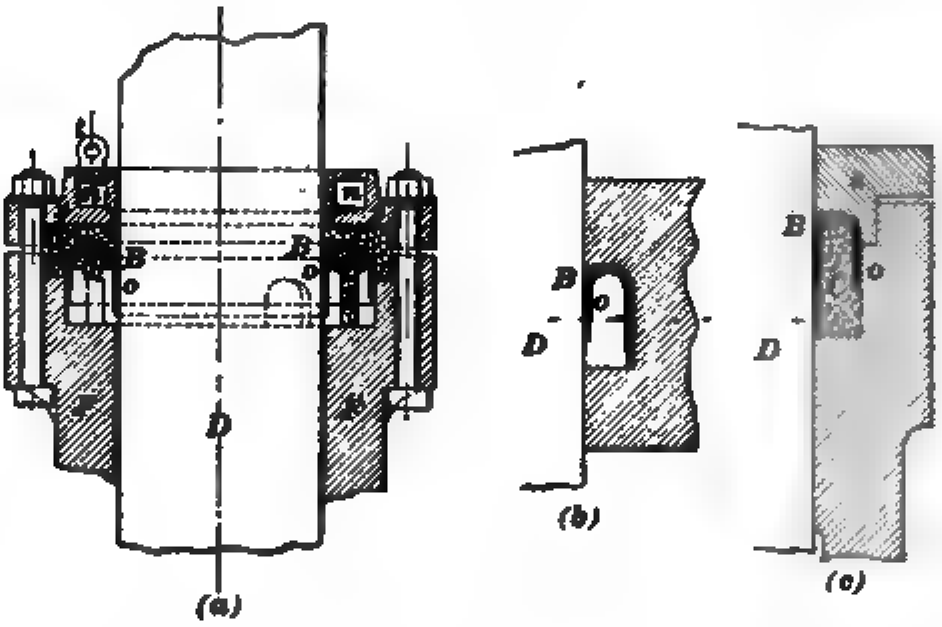


FIG. 3.

which prevents the severe pressure of the leather against the plunger at B. A more elaborate packing is shown at (a); the gland s is lined with a brass ring m, which holds the leather o down on a brass supporting ring p. A chamber u in the gland serves to hold oil for lubricating the plunger

The form of packing shown at (b) is cheap, but in addition to the difficulty of inserting the leather, it is difficult to cast the recess so that it will fit the leather properly. In either of the forms shown in (a) and (c), the gland can be accurately turned to bear against the curved portion of the leather, thus forming a better support and increasing the life of the packing.

5. Fig. 4 shows an inside-packed plunger with a removable stuffingbox designed for hemp packing. This construction is better than merely providing a close-fitting bushing, especially when the water is gritty and thus liable to wear the plunger.

Inside-packed plunger pumps have several disadvantages. When the packing becomes worn, the heads of the pump cylinder must be removed in order to tighten or renew it, and,

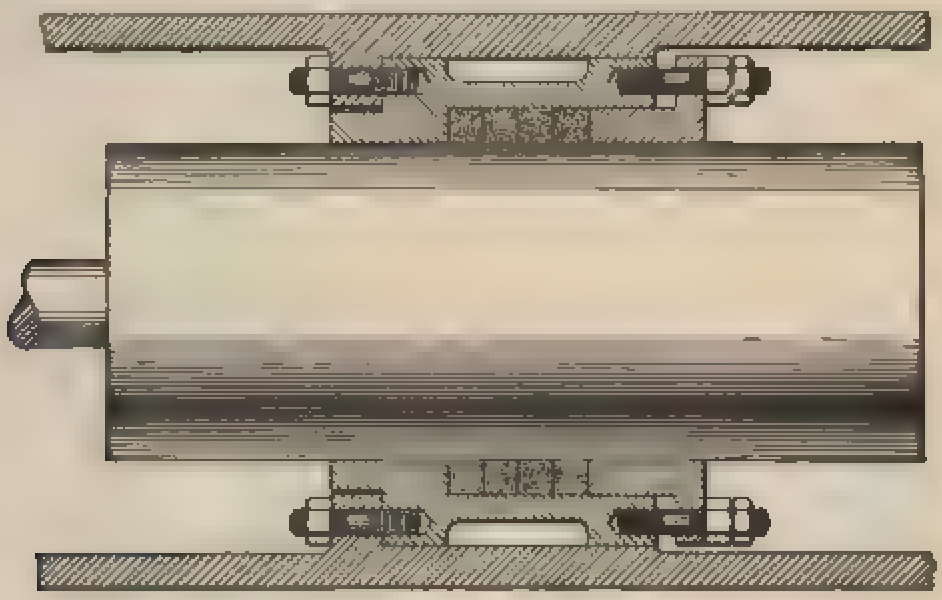


FIG. 4.

besides, there is no way of detecting leakage when the pump is working. With gritty water, especially when working under high pressures, these disadvantages become serious.

6. Fig. 5 shows a good arrangement of plunger, stuffingbox, and gland. This type of plunger and stuffingbox is

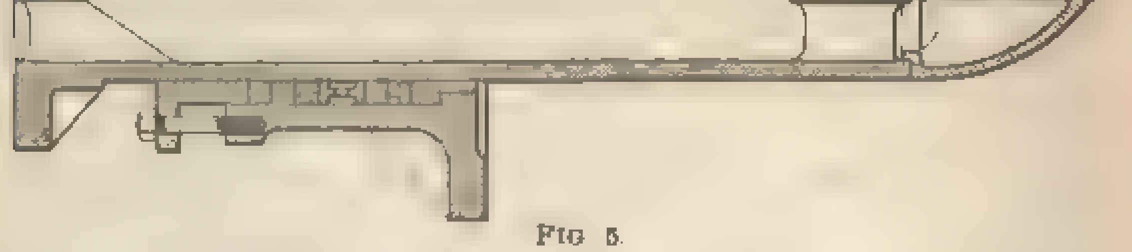


FIG. 5.

much used in mining pumps. The plunger cap *a* is made of acid-resisting metal, while the plunger *b* proper is made of cast iron, it having been found in mining work that the

plunger cap or point is the only part that is attacked by acid water. Apparently the play of the plunger through the stuffingbox and grease prevents the water attacking its surface. An improved form of **grease ring** is shown at *c*. This ring fits into the stuffingbox and is placed between the rings of fibrous packing. It is recessed both inside and outside and has several holes by which the outside recesses connect with the inside recesses. The outside recess is in connection with the grease cup *d*, which is provided with a cock. When it is desired to grease the plunger, the cock is opened and the grease forced in the space around the grease ring by the screw *e* on top of the grease cup. This is done once or twice during the day, and the cock is then closed so as to relieve the grease cup of the water pressure and to prevent consequent leakage. The stuffingbox is bolted directly to the pump chamber, which may be of any type, but for high-pressure mine work it is generally circular. This type of plunger and stuffingbox has been used with much success in the anthracite coal regions.

PUMP PISTONS.

7. Pistons for force pumps are made in a variety of forms. Fig. 6 shows a piston with fibrous packing held in place by a follower. The follower is fastened to the piston by means of an extension of the piston rod beyond the nut that holds the piston in place.

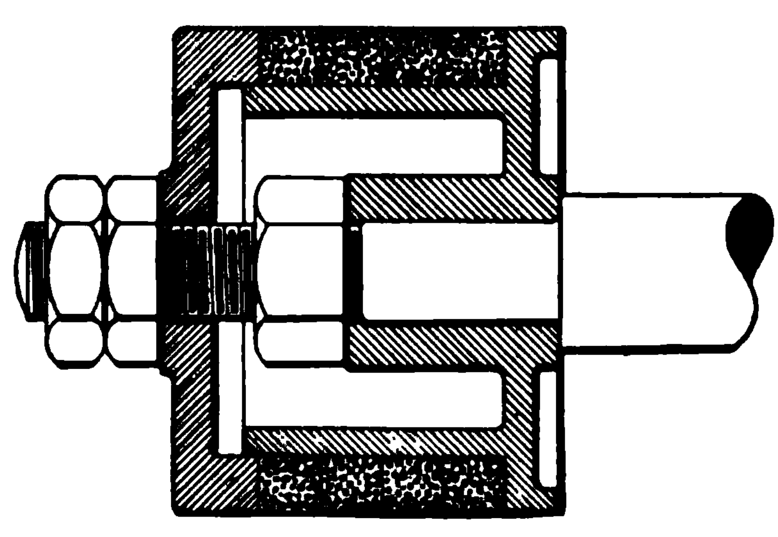


FIG. 6.

8. An excellent packing for small pistons is shown in Fig. 7. It consists of a metallic piston made up in three parts, between which are clamped two cup leathers, as shown.

9. Pistons for suction and lift pumps must be provided with valves that allow free passage for the water through

the piston in one direction and prevent its return. These

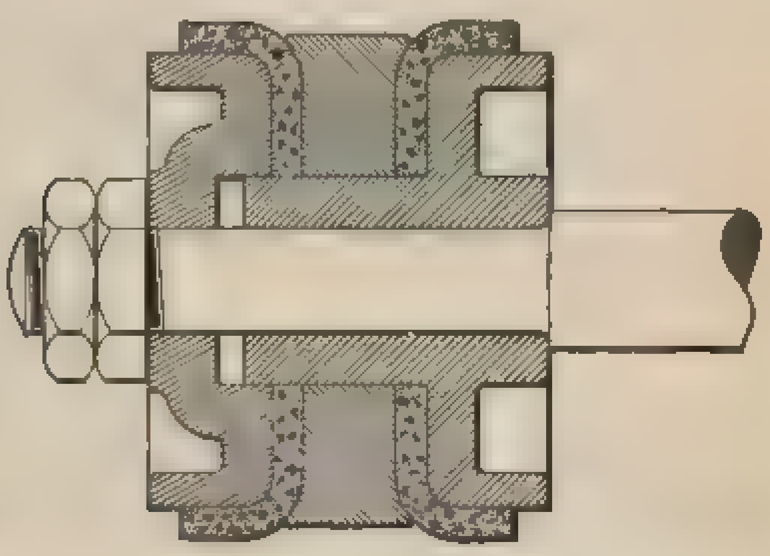


FIG. 7

valves may be of any design that will furnish the required area of passage and at the same time will be strong enough to withstand the pressure of the water.

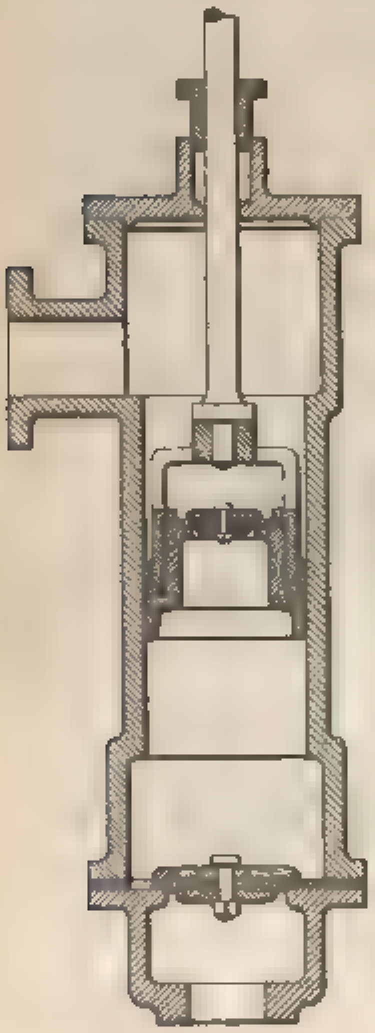
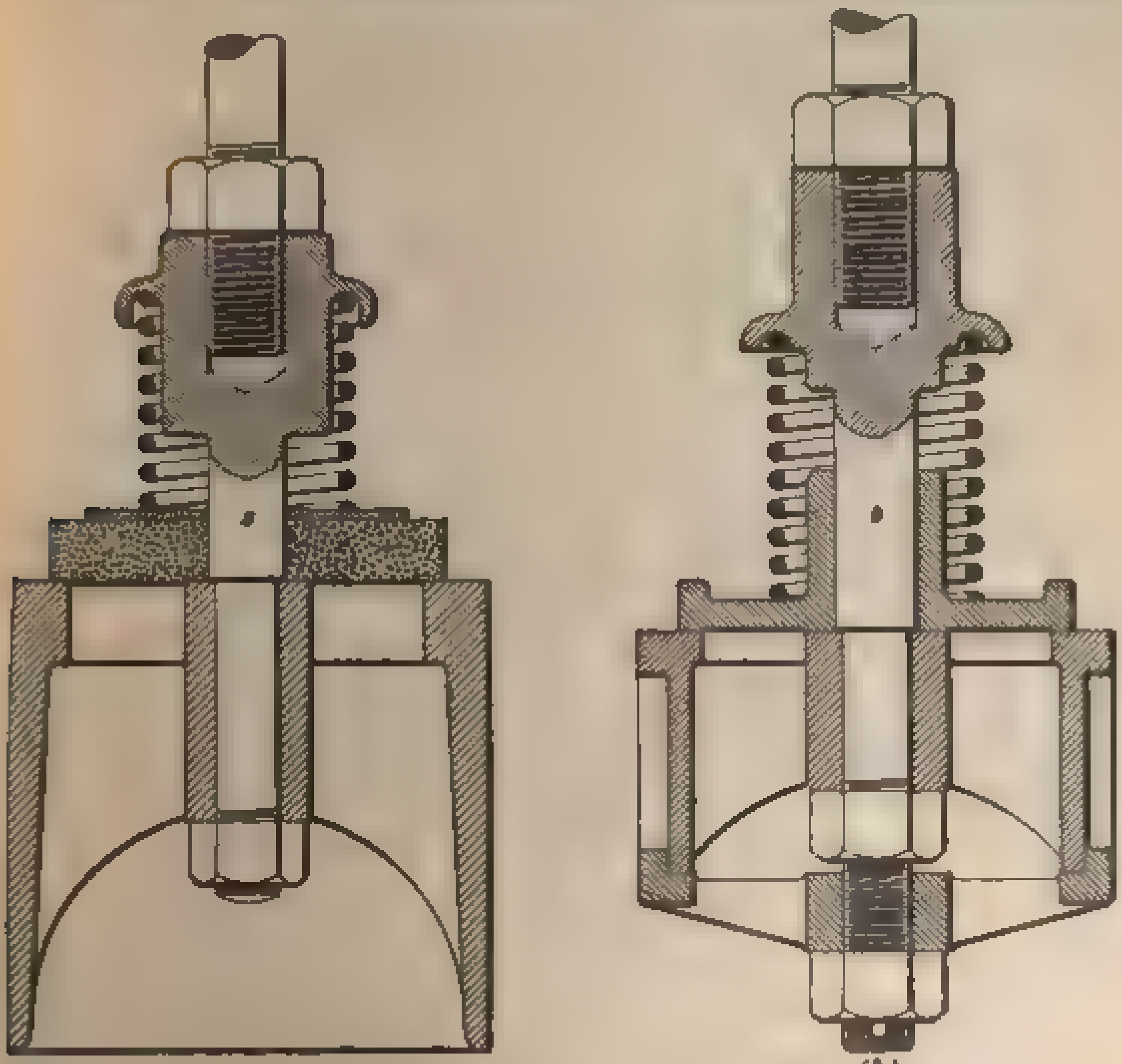


FIG. 8.

10. For small pumps and moderate lifts, leather **clack valves,** Fig. 8, are often used. They consist simply of a leather disk held at one side and strengthened by a metal plate on top. The leather when wet forms an excellent hinge and a tight valve. Leather clack valves are also used for the suction and delivery.

11. For lift pumps working under high pressures, the valves shown in Fig. 9 give good results. The piston shown at (*a*) has a rubber disk valve working on a gridiron seat. The valve is guided by a central spindle *s* and is held on its seat by a light helical spring that acts on a plate on top of the rubber disk. This piston is very long and has no separate packing.

12. The valve shown at (*b*) is for very heavy pressures. It consists of a metal disk guided by a central spindle *s* and held down by a helical spring in the same manner as the



(*a*) (*b*)

FIG. 9.

rubber valve. The piston is made with a follower plate for the purpose of holding a fibrous packing in the same manner as the piston shown in Fig. 6.

PUMP VALVES.

REQUIREMENTS.

13. The most important details of a pump of any kind are the valves. They must be so designed and constructed that they will fulfil all the following conditions as thoroughly as possible:

(*a*) They must open freely under a light pressure

(*b*) The net area of the passages through the valves should be great enough to limit the velocity of flow through them to 240 feet per minute

(*c*) The lift of the valves should be small

(*d*) The passages for the water should be as direct as possible.

(*e*) The valves must close tightly under all conditions

(*f*) The valves and their seats must be durable and of such materials as are not easily affected by the impurities in the water.

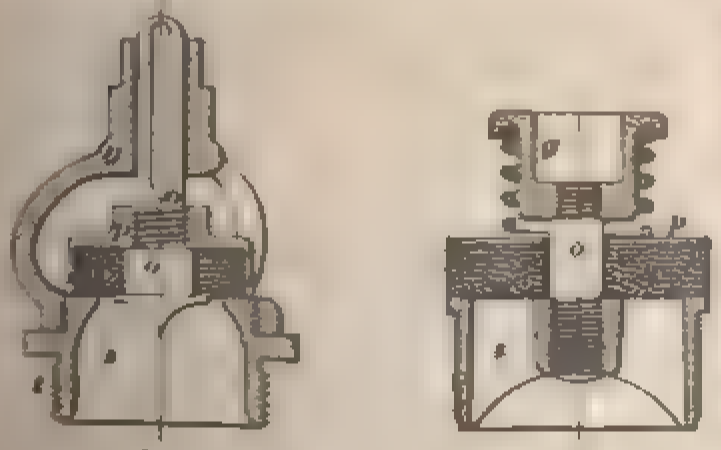
(*g*) The valves must return to their seats quickly and without shock as soon as the current through them is stopped.

(*h*) The valves and seats must be easily repaired or removed when worn

A great variety of valves have been designed with a view of satisfying these requirements, taking into consideration the widely varying conditions under which pumps must work.

CONSTRUCTION.

14. Disk Valves.—Fig 10 shows two valves of a type much used in all classes of pumps for ordinary pressures and service The valve *v* consists of a vulcanized India rubber disk that rests on a gun-metal or brass seat *s*. The seat is threaded at *t*, so that it can be screwed into the deck of the valve chamber and thus can be easily removed The part of the pump chamber that contains the valves is usually called the **valve deck,**



(*a*) (*b*)

FIG 10

and it is spoken of as the **suction valve deck** and **delivery valve deck** in accordance with the kind of valves it carries. In the design shown at (*a*), the valve is fastened to a spindle *o* by a cap *p*. The spindle is guided by a cage-shaped guard *g* screwed on to the valve seat. The lower end of the spindle is made conical, so as to change the direction of motion of the water gradually and to reduce the resistance to flow. In the design shown at (*b*), the spindle *o* is screwed into the valve seat and carries a guard *g*. A helical spring between this guard and the plate *p* helps to seat the valve quickly.

The size of these valves varies from 2 to 6 inches in diameter, the most common size for ordinary conditions being 3 inches.

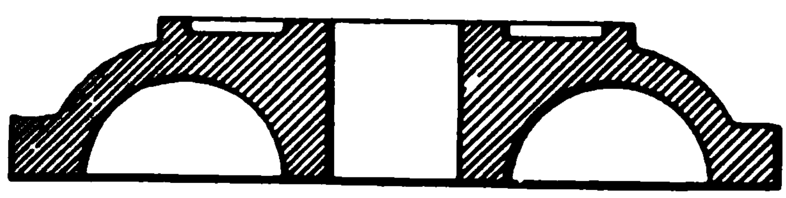


FIG. 11.

15. When used for pumping *hot* water, the disk must be made of a composition that will not be affected by the heat and for very high pressures metal disks are used, generally of the form shown in Fig. 11.

16. Fig. 12 shows the construction of a large disk valve, such as is often used in mine pumps. The valve seat *A* is held in place by the flange *B* and is perforated, as shown in the top view of the seat, by a large number of small holes. The valve *C* is made of soft rubber and is placed within the bronze or composition cap *D*. The head of the bolt *E* forms a stop and the spring *S* assists the valve in closing.

17. Clack Valves.—A section of a clack valve is shown in Fig. 13. The **clacks** *A* and *B* are lined with leather on the bottom so as to make a tight fit on the seat without having to do much fitting. A stop *C* prevents the valves opening too far, while *E* is the pin on which the clacks are hinged. A cylindrical casing *D* forms the valve seat; it may be easily renewed when worn. These valves are of the type known as the **butterfly valve,** and are much used for pit pumps at mines on account of their cheapness and simplicity of construction.

18. Single-Seat and Double-Seat Valves.—A **single-seat valve** that is suitable for high pressures, up to heads of 500 feet, is shown in Fig. 14, where *A* is the valve; *B* is

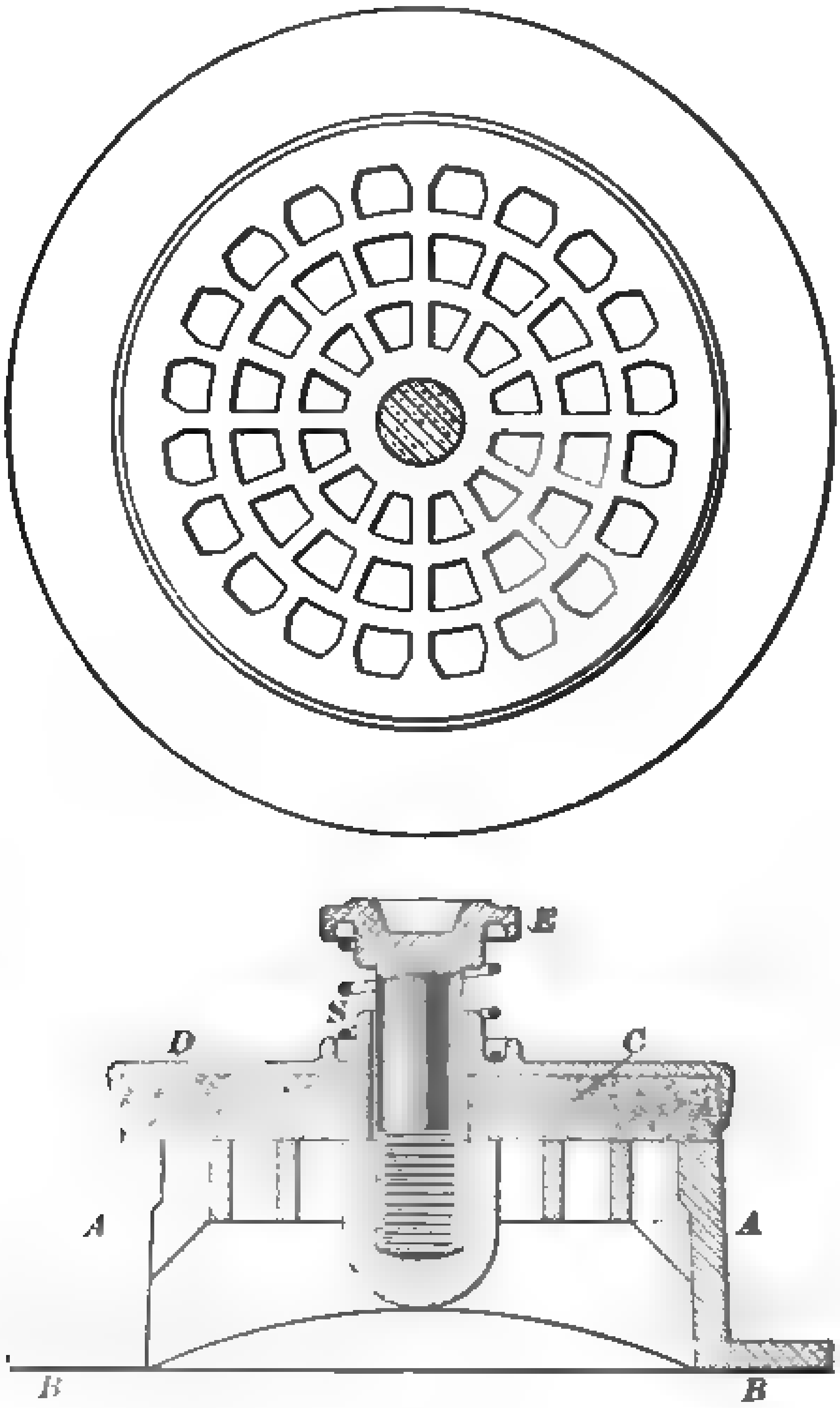


FIG. 12.

a stem solid with the valve that acts as a guide inside the bearing *D*; and *C*, *C*, *C*, *C* are rubber rings which are kept in position by means of the stem and are separated by the

washers *E*, *E*, *E*. These rings prevent shock as the valve lifts and also help to close it quickly, thus serving the same purpose as the helical spring in Fig. 10 (*b*).

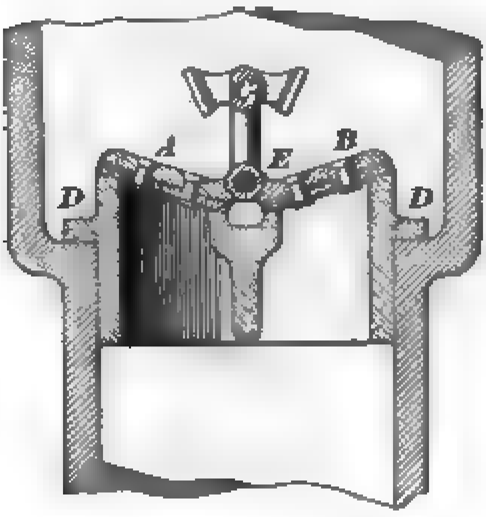


FIG. 13.

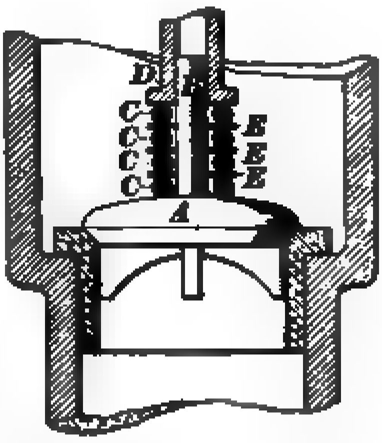


FIG. 14.

19. A section of a **Cornish double-seat valve** is shown in Fig. 15. This valve gives excellent results when used in

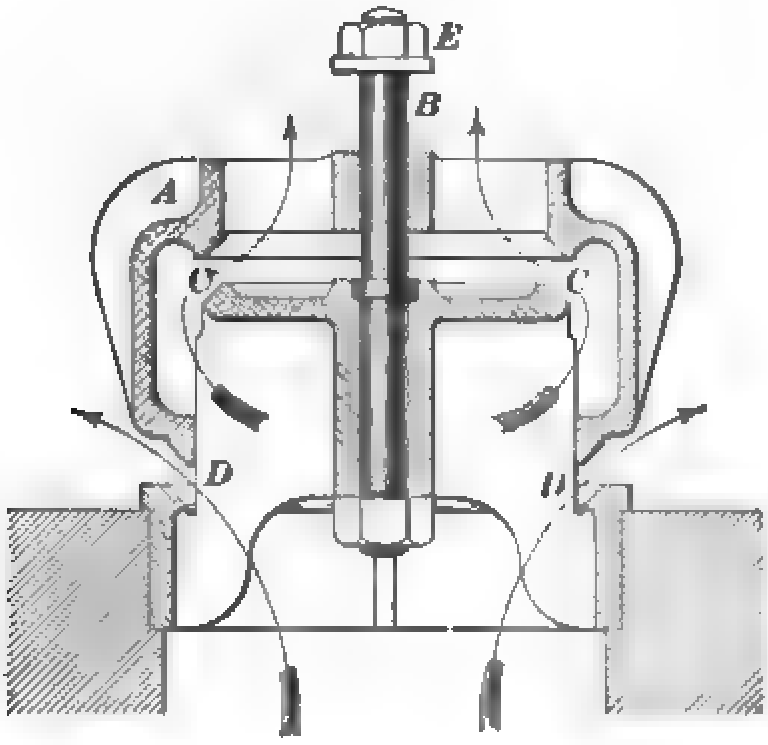


FIG. 15.

large pumps working under high pressures and has been applied to pumps working under heads up to 700 feet. It is called a *double-seat* valve because it has two seats and two

openings for discharge. The casing *A* slides on the vertical stem *B*, its lift being regulated by the nut and washer *E*; when down, it rests on the valve seats *C* and *D*. When the pressure below becomes greater than that above, it raises the casing, and the water is discharged through the circular openings at *C* and *D*. The rib around the outside of the casing is for the purpose of strengthening it. The valve seats are conical. The figure shows that one opening discharges the water under the lower edge of the valve and the other through the inside.

20. Wing Valves.—The **wing valve** shown in Fig. 16 (*a*) is largely used in power pumps for feeding boilers and in

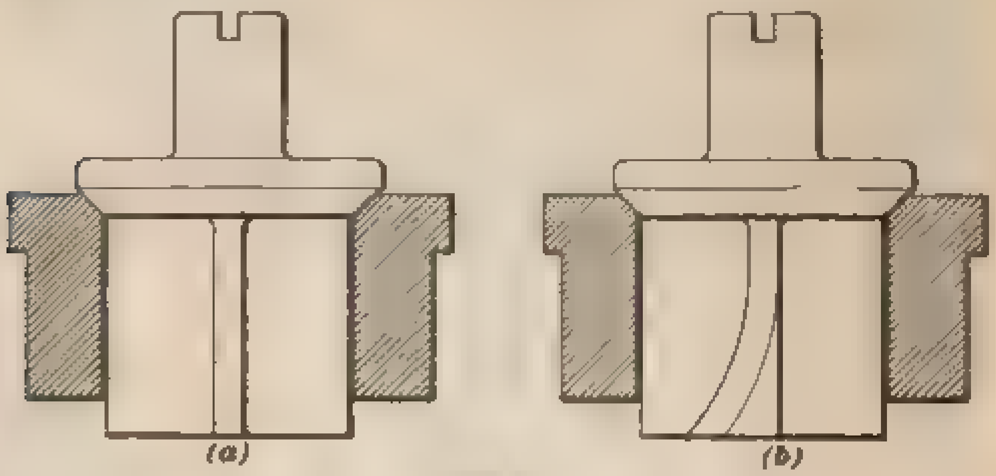


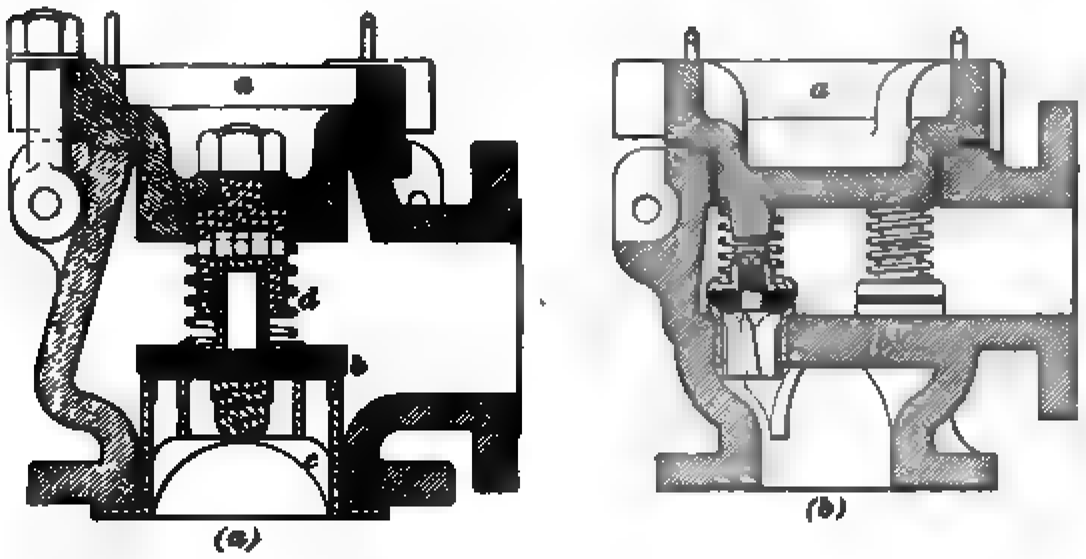
FIG. 16

hydraulic pumps for high pressures. The valve and seat are made either of hard brass or of gun metal and are ground together to secure tight closing. The lower portion of the wings is sometimes curved as shown at (*b*), the object being to give the valve a partial rotation at each stroke of the pump. This compels it to seat at a new place with each stroke and tends to wear the valve and seat more evenly.

21. Pot Valves.—Fig. 17 (*a*) is a sectional view of a **pot valve.** This type of valve is used principally on mining pumps for lifts up to 1,000 feet. They are made separate from the pump chambers and may be readily replaced when broken or worn. The cover *a* is secured by hinged bolts, so that it may be quickly removed for access to the valve *b* and the valve seat *c*, which is made of composition and pinched

between the pot and the pump chambers. The valve spring *d* surrounds the valve guide *c*.

22. Fig. 17 (*b*) shows a type of pot valve used for high lifts up to 1,200 feet. The valves are made small and faced with hard rubber; a group of them is placed in one heavy



(*a*) (*b*)

Fig. 17.

pot which is bolted to the pump chamber. Access to the valves may be had by removing the cover *a*. The valve seats are made of composition bushings forced into the valve deck *b*.

AIR CHAMBERS.

PURPOSE.

23. Even in double-acting pumps there is an interruption of the flow at the end of the stroke, when the piston changes its direction of motion. This has the effect of bringing the column of water in the suction and discharge pipes to rest at the end of each stroke, and this column of water must be set in motion again as the next stroke is made. If the pipes are long, the force required to stop and start the water will be very great, and there will be a severe shock at the end of every stroke that will absorb power and subject the pump and pipes to great stresses.

This difficulty is removed and the flow through the pipes is made more continuous and steady by the use of **air chambers.** An air chamber is a vessel containing air and is attached either to the pump just outside of the discharge valves or to the discharge pipe near the pump. While small duplex pumps are often run without an air chamber, it is better in general to fit one to all pumps, since its effect will always be beneficial.

DELIVERY AIR CHAMBERS.

24. Principle of Action. Fig. 18, which shows an air chamber attached to the discharge pipe of a single-acting

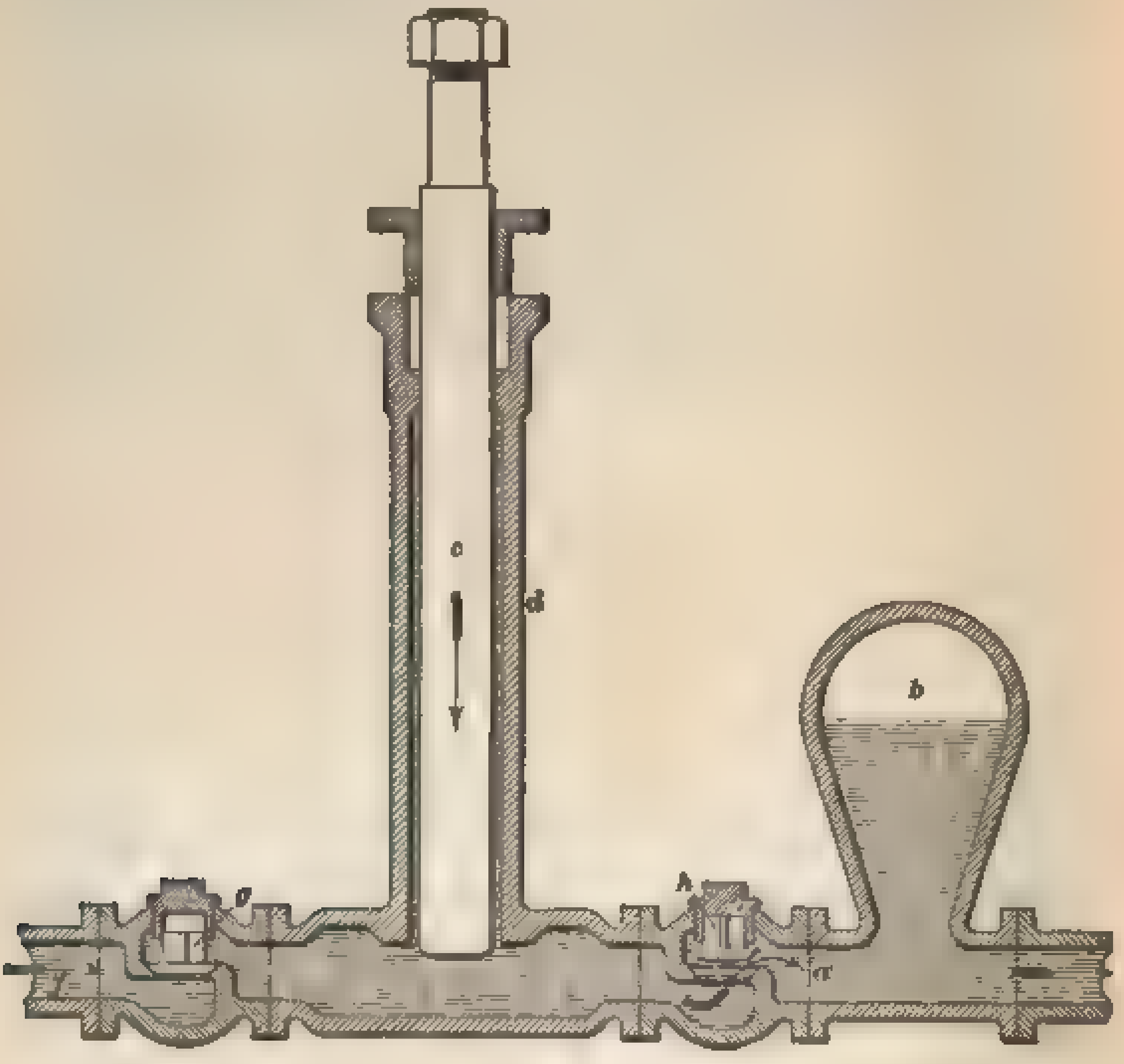


Fig. 18

plunger pump *d* for boiler feeding, will illustrate the principle of action of an air chamber. The water, after being

drawn in through the pipe *f* past the valve *g*, is forced by the plunger *c* past the valve *h* into the discharge pipe *a*, part of it flowing into the air chamber *b* and compressing the air therein. When the plunger reaches the end of its stroke and no more water is being forced into the discharge pipe, the compressed air in the air chamber forces the extra water out through the discharge pipe. In this way the air chamber acts as a *reservoir* that receives its supply during the inward motion of the plunger and gives it out again in a nearly steady stream. The air in the air chamber acts as a spring that absorbs the extra force during the inward stroke of the plunger and gives it out during the return stroke, thus relieving the pump and pipe of shocks and providing a nearly constant rate of flow from the discharge.

25. Size of Delivery Air Chamber.—The proper size of an air chamber depends on the type of pump, the speed at which it works, the length of the discharge pipe, and the pressure head against which the pump works. For ordinary double-acting pumps working against moderate pressures and at ordinary speeds, the cubical contents of the air chamber should be not less than 3 times the piston displacement. For pressures of 100 pounds per square inch and upwards or for high piston speeds (as in the case of fire pumps), the capacity of the air chamber should be at least 6 times the volume of the piston displacement for a single stroke.

26. Loss of Air.—Under the increased pressure in the air chamber, the air is absorbed by the water and gradually passes off with it. In this way all the air will finally pass off and the chamber will be made useless if no means are provided for renewing the supply.

27. A simple device for maintaining the supply of air in the air chamber of large pumps is shown in Fig. 19. A piece of $2\frac{1}{2}$-inch wrought-iron pipe *c* about 30 inches long is connected to the end of the pump cylinder *a* in a vertical

position, by means of a gate valve *b*, or cock. A $2\frac{1}{2}$-inch T *d* at the upper end of this pipe is connected at one end of the run with a $1\frac{1}{4}$-inch check-valve *e* opening inwards, and at the other end with a $\frac{3}{4}$-inch check-valve *f* that opens outwards. The valve *f* is connected with the air chamber through the pipe *g*.

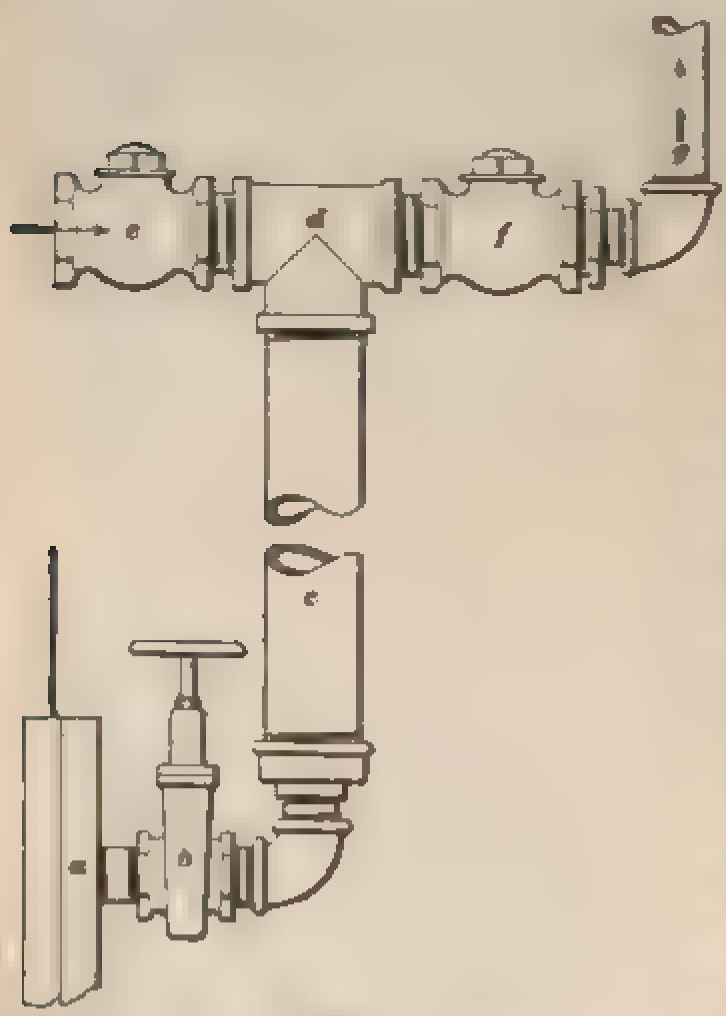


FIG. 19.

This air pump is operated as follows: When the pump is working, open the valve *b* to fill the pipe *c* with water; then partially close *b* until the check-valves *e* and *f* begin to work. This is easily determined by the click of the valves when seating. Its working may be described thus: When the valve *b* is opened, water fills the pipe *c* from the pump cylinder *a* during the discharge stroke of the pump. By partly closing *b* when *c* is full, the pump during the suction stroke will draw a part of the water from *c*, and air will flow in through *e* to take its place. During the next discharge stroke of the pump, more water is forced into *c*, driving the air out through *f* and *g* into the air chamber. If *b* is opened too wide, all the water will be drawn out of *c* during the suction stroke and air will be drawn into the pump cylinder from *c*; but by properly regulating the opening, a column of water is kept in *c*, which acts as a piston that moves with the strokes of the pump and pumps air into the air chamber.

28. Alleviator. When pumps work under pressures greater than that due to a 350-foot lift, air chambers are not of very much service, owing to the fact that the air escapes from the air chambers either through the pores of the iron or at the joints, or it is absorbed and carried off by the water; in such a condition an air chamber gives the pump no relief whatever. To obviate this defect **alleviators** are used. An alleviator is shown in Fig. 20. It consists of a plunger *a* working through a water-packed stuffingbox. On top of the plunger are arranged springs that may be in the form of rubber buffers or helical coil springs. In the type shown rubber buffers *b*, *b* are used, which are confined by the tie-rods *c*, *c*, the yoke *d*, and the plates *e*, *e*. When the pressure in the pipe exceeds the working pressure, the plunger *a* is forced out through the stuffingbox and relieves the pump of the shocks that would otherwise occur. Alleviators may be placed anywhere on the delivery pipe, but are preferably placed in such a position that the direction of the moving water is in line with the plunger *a*.

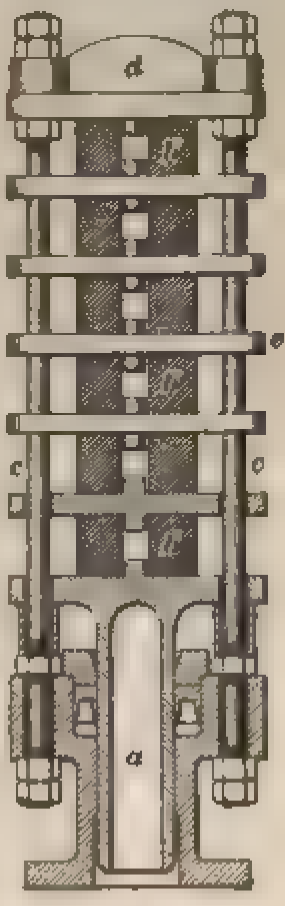


FIG. 20.

SUCTION AIR CHAMBERS.

29. Purpose.—With a long suction pipe or a pipe with numerous bends and valves, the resistance to the flow of the water through it will be considerable, and a great deal of force will be required to start and stop the water in it with each stroke of the pump. In some cases the force required is so great that the pressure of the atmosphere is not sufficient to set the column of water in motion quickly enough to fill the pump chamber as fast as the piston moves. This makes the action of the pump imperfect and causes a

severe blow, called the **water hammer,** when the piston again meets the inflowing water.

30. The difficulty mentioned in Art. **29** can best be remedied by the use of a chamber, called a **vacuum chamber** or a **suction air chamber,** attached to the suction pipe as near the pump as possible. In its general form a vacuum chamber resembles an air chamber, but the pressure in it instead of being greater is always less than the atmospheric pressure. When the pump is drawing water, the air in the vacuum chamber expands and forces the water below it into the pump; at the same time the pressure of the atmosphere forces water in through the suction pipe to balance the reduced pressure in the vacuum chamber. The vacuum chamber is again partly filled and the air in it is compressed during the discharge stroke of the pump. It thus acts as a reservoir that receives from the suction pipe a nearly steady supply, which is given up intermittently to the pump.

31. Special Form of Suction Air Chamber. Fig. 21 shows a special form of a suction air chamber in diagram-

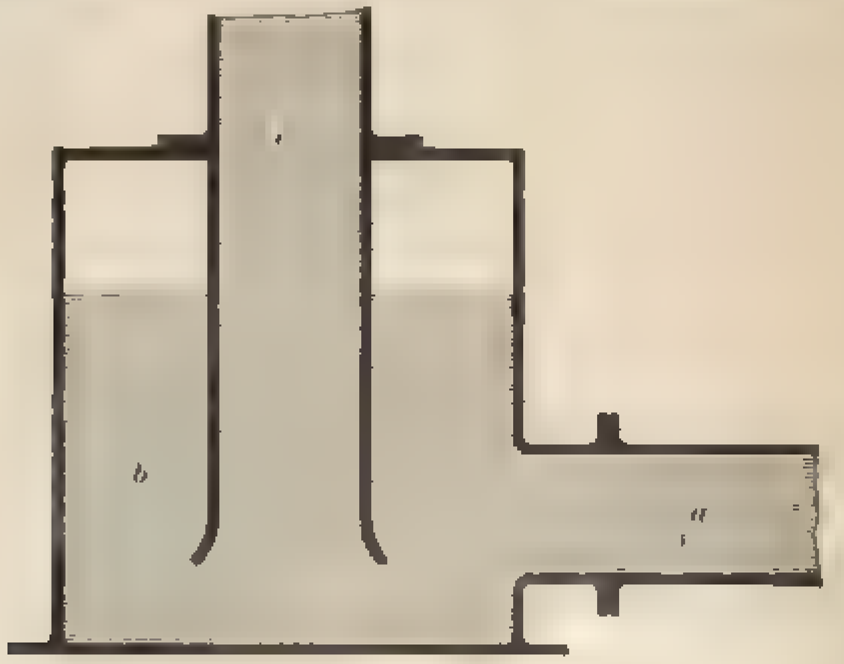


FIG. 21.

matic form. The suction pipe *a* connects to a suitable chamber *b*, which has a tube *c* projecting downwards to

within a short distance of the bottom. The tube *c*, which is called a **draft tube,** connects to the pump chamber. When water first flows into the chamber *b*, it entraps some of the air as soon as the water seals the bottom of the draft tube; this air is then compressed while the water flows up the draft tube, and by its expansion and compression permits a steady flow in the suction pipe.

32. Size of Vacuum Chambers.—For ordinary cases, the vacuum chamber may be made half the size of an air chamber working under the same conditions. A good rule is to make the cubic capacity of the vacuum chamber for a single pump twice that of the displacement of the piston for a single stroke.

33. Location.—Suction and delivery air chambers should, if possible, be placed at a bend in the pipe and close to the pump and in such a position as to be in line with the flow of water in the pipe. If placed at right angles to the flow of water, as in Fig. 18, their efficiency is somewhat impaired. Both suction and delivery air chambers should be provided with glass water gauges so that the height of the water can be determined at a glance. It is not customary to provide the air chambers of small pumps with water gauges.

PUMP FOUNDATIONS.

GENERAL CONSIDERATIONS.

34. The foundation for pumping machinery depends entirely on the type of pump. Generally speaking, much less foundation is required than for steam engines occupying about the same space. Direct-acting duplex pumps probably require the least foundation of any kind of steam pump, for here the piston and plunger motion is almost opposite and the balancing of the machine in line with the plunger motion is complete, and the strains due to reversing are contained almost wholly within the machine itself. Small duplex-pump foundations are made of a solid mass of brick or

concrete, while large pumps are often set on separate piers, one for the water ends and one for each pair of steam ends in case of a duplex, compound, or triple-expansion engine. Of course, the foundations must go down to sufficiently hard soil to bear up the weight of the pump, or if the soil be loose sand or gravel, the foundation must be spread out sufficiently to insure the pressure not exceeding, say, 1 ton per square foot. The foundation should go deep enough to allow the surrounding soil sufficient hold upon it to keep it firm and steady. The minimum depth for a small pump should not be less than 2 feet. Single-cylinder pumps require a somewhat heavier foundation than duplex pumps, owing to the greater shocks to which they are subjected.

35. Crank-and-flywheel pumps require considerably more foundation than direct-acting machines, on account of the much higher speeds possible and the weight and lack of balance of the reciprocating parts. Crank-and-flywheel pumps of the controlled valve type, as the Riedler pumps, which usually run at a high speed, require foundations fully as heavy as those for steam engines of equal size.

MATERIAL AND FOUNDATION BOLTS.

36. Foundations should be built of hard brick laid in cement mortar, concrete, or, in the case of large pumps, of stone, if it can be readily secured. All pumps should be held down by foundation bolts. In the case of small pumps the bolts are provided with a steel or wrought-iron plate washer built solidly into the foundation, while large pumps have tunnels or pockets for access to the lower foundation washer and nut. If the foundation bolts are built in solid, box washers should be used.

FOUNDATIONS FOR LARGE PUMPS.

37. In the case of large vertical pumping engines, the masonry required to form the pump pit and to support the superstructure is of ample mass for all foundation purposes; in fact, large arched chambers and tunnels are often used to

save foundation materials in this class of pumping engine. These large pumping engines are often located at or near a water supply where the soil has not sufficient rigidity to support the weight. In this case piling must be resorted to, on which the foundation proper is constructed.

USE OF FOUNDATION TEMPLET.

38. A foundation templet should always be used in which the foundation-bolt holes are carefully laid off, preferably from the actual castings, and the various heights of bosses or thicknesses of casting through which the bolts pass are marked. The templet should be carefully set with reference to the suction and delivery connections, so that when the pump is set up, the fittings and pipes will connect up properly. In large pumps it is customary to arrange the pipe connections in such a way that a short space is left between the piping and the pump. This space is then measured after the pump and piping are in place, and a distance piece is made to suit the measurement and then put in place.

FOUNDATIONS FOR SMALL PUMPS.

39. Small pumps of the single-cylinder and duplex type are usually provided with two points of support only, one of which is rigidly bolted to the foundation, while the other is left free. This prevents the pump being thrown out of line, if properly constructed originally. When both the steam and water ends are bolted down, care must be taken not to twist or throw the pump out of line. In making the steam and water connections, the pipes should come fair to their connections and should not be sprung into place. Stresses on the pump structure due to winding foundation surfaces and sprung pipe connections should be guarded against, particularly with steam-thrown valves, as these are very sensitive and must be perfectly free. Any slight springing of the valve chamber will bind the valve and prevent its operating.

PIPING.

SUCTION PIPING.

40. Location of Pump in Respect to Supply.—Before a pump can be properly located the location of the source of supply of the liquid to be pumped must be taken into consideration. Since the atmospheric pressure of 14.7 pounds to the square inch will balance a column of water 34 feet high, it is evident that with that atmospheric pressure the pump must not be placed more than 34 feet vertically above the surface of the water to be pumped. But since a perfect vacuum cannot be obtained by mechanical means, and since the flow of the water is retarded by friction in the pipes and passages, the limit of vertical lift by atmospheric pressure is reduced to about 28 feet at sea level in actual practice. The actual lift, precisely as the theoretical lift, varies with the atmospheric pressure, and hence will become smaller with an increase of altitude above sea level, since the air becomes lighter and its pressure less.

41. Run of Suction Pipe.—The pump should be placed as near the source of water to be pumped as is possible, both vertically and horizontally. The suction pipe should be as straight as possible. If bends are necessary, they should be made by bending the pipe to a long radius or by using long turn fittings. The suction pipe should be one diameter from end to end; all enlargements or reductions in size tend to disturb the uniform flow of the water so essential to a proper filling of the pump chamber. If from necessity the suction pipe is very long, it will be well to increase the size somewhat; the reduction at the pump chamber should then be made by a long conical fitting. For ordinary service pumps the diameter of the suction pipe should be such that the velocity does not exceed 200 feet per minute, assuming that the flow of water is constant. If the vertical lift be high, a suction air chamber should be provided; this will

add much to the uniformity of the pump supply. A foot-valve should also be provided when the lift is high.

42. Foot-Valves.—A foot-valve is a check-valve placed at the lower end of the suction pipe below the water level in the source of supply and opening towards the pump. Its purpose is to prevent the suction pipe emptying while the pump is at rest and to prevent the water in the suction pipe slipping back while running. When the water flows to the pump by gravity, a foot-valve is superfluous; but when the water is lifted by suction it is often fitted, since it will insure a prompt starting of the pump, providing that it is tight enough to hold the water in the suction pipe. In very cold weather and in exposed locations, the foot-valve constitutes an element of danger when the pump is out of use, since it prevents the emptying of the suction pipe. The water in the latter may freeze and burst the pipe. To prevent this, a drain may advantageously be fitted to the lower end of the suction pipe, which is used in cold weather to empty the pipe if the pump is to stand idle for a long time.

43. When foot-valves are used, a relief valve may advantageously be placed on the suction pipe. Generally, the suction pipe is made considerably lighter than other parts of the pump, and if the suction valves should leak when the pump is standing or if the priming pipe be left open, the full pressure of the delivery water will come on the suction pipe and foot-valve, which are not usually designed to withstand such pressures. The relief valve, which should be set to relieve the pipe at a pressure well within its safe strength, prevents overstraining of the suction pipe from this cause. Foot-valves should be chosen with the greatest care; they should be simple and, preferably, of the weighted-lift type or clack valve, and should have at least 50 per cent. excess of area over the suction pipe.

44. Settling Chamber.—If the water to be pumped is gritty or contains foreign substances, a settling chamber is sometimes used, especially when pumping water holding but

a small quantity of sand in suspension. This consists of an iron box conveniently arranged in a horizontal pipe. It is usually of large relative capacity, a settling chamber for a 2-inch pipe being 2 feet × 2 feet × 3 feet long The pipes enter and leave from opposite sides and near the top. The increased volume of the large box allows the water to move very slowly across the box, giving the suspended sand time to settle to the bottom. The settling chamber should have a removable cover for the purpose of removing the settlings. This device is used on small pumps working on artesian wells.

45. Suction Basket and Strainer.—More universal arrangements for keeping back foreign matter from the working barrel of the pump are the **suction basket** and the **strainer.** The suction basket is usually placed on the bottom of the suction pipe and consists of a box variously shaped and perforated with strainer holes or provided with screens. The suction basket so placed is being replaced by a different form of strainer, which consists of a chamber placed in the suction pipe, located in an accessible position and provided with strainer plates so made that they can be readily removed for cleaning This strainer is sometimes connected directly to the pump, but it should not be so placed that it will interfere with removing the water-cylinder heads. A short piece of pipe between the strainer and pump nozzle will avoid this interference. The objection to the suction basket on the bottom of the suction pipe is its inaccessibility for cleaning and inspection, a feature that is overcome by the strainer.

DELIVERY PIPING.

46. Run and Valves.—While the suction pipe is very important and must be most carefully laid out and has much to do with the location of the pump, the delivery pipe should not be neglected. A careful adjustment between the supply and delivery pipes should be made in order to produce the

best effect of the whole plant. The delivery pipe should as far as possible be a plain, straight pipe from pump to terminal; when bends are necessary, they should be by as long sweeps as possible. A gate valve or check-valve should be placed near the pump. The check-valve serves the double purpose of relieving the pump of pressure when starting up, allowing it to take hold of the water more quickly, and also holds the water back from the pump when inspection and repairs to the water end are necessary. If a check-valve is not used, a gate valve should be placed at or near the pump delivery to hold back the water in case of repairs to the pump end or accident. This valve should always be a straightway gate valve giving the full clear opening of the pipe.

47. Velocity of Flow.—The velocity of the water flowing through the delivery pipe for direct-acting pumps should not much exceed 330 feet per minute, while for large crank-and-flywheel pumping engines the velocity of water in both suction and delivery pipes is about 300 feet per minute. If the suction pipe is made small, the pump will fail to fill and the plunger will strike the incoming water on its return stroke, producing a violent and dangerous shock. If the delivery pipe is made small, the cost of power required to force the water through the pipes at a high velocity will very quickly overrun the interest and depreciation on a larger pipe.

AUXILIARY PIPING.

BY-PASSES.

48. Water-End By-Pass.—**By-pass pipes** are pipe connections from above to below the delivery-valve deck and are of much more use on crank-and-flywheel pumps than on direct-acting machines. In the case of compound pumps, when starting up, the force of the full steam pressure on the high-pressure piston is not sufficient to move the plungers

against the resistance due to the head of the water in the delivery pipe; but by opening the valve (which, by the way, should always be a gate valve) in the by-pass piping, the pressure on the plungers is relieved for a sufficient number of strokes to allow the steam to reach the low-pressure piston, when the combined force of the two pistons will do the work and the by-pass pipe can be closed.

49. By-pass water pipes have another function on crank-and-flywheel pumps. Unless these machines are fitted with very large flywheels, their limit to slow running is often not as low as desired. By opening the valve in the by-pass pipe, part of the water can be returned to the pump chamber and the amount of water actually pumped reduced to any desired quantity permitted by the size of the by-pass. It should not be overlooked that this is accomplished at a very considerable loss of efficiency, because it takes the same power to move the by-pass water as it does to do the actual pumping, comparing equal quantities. By-pass pipes are usually made 2½ per cent. of the plunger area.

50. Steam-End By-Pass.—It is common practice to fit the steam cylinders with by-pass pipes, allowing high-pressure steam to act on the low-pressure piston in starting, but these pipes are usually so small, compared with the diameter of the low-pressure piston, that the by-pass is unable to hold any pressure behind the low-pressure piston when it is moving. By-pass steam pipes have their proper use in warming up the low-pressure cylinder and connections, [illegible] cranks and flywheel pumps to move the [illegible] off the dead center.

PRIMING PIPE.

51. [illegible] priming or **charging pipe** is a small pipe run [illegible] pipe beyond the check-valve or delivery [illegible] chamber of the pump. It is par[illegible] case of long suction lifts to fill the [illegible] suction pipe with water, taking up all

clearances and helping the pump to take hold of the water quickly. This pipe may be from $\frac{3}{4}$ of 1 per cent. to 1 per cent. of the area of the plunger; its size is a matter of little importance, but it should be large enough to fill the suction pipe and pump chamber in a reasonable time, which will depend somewhat on the size and design of the pump chamber and the length of suction pipe. A pipe much larger than 1 per cent. of the plunger area will be required in the case of long inclined or horizontal suction pipes.

WASTE DELIVERY PIPE.

52. A **waste delivery** or **starting pipe** that can be led into any convenient place of overflow should be provided so that the pump, in starting, can free itself of air, for it often happens that a pump refuses to lift while the full pressure against which it is expected to work is resting on the delivery valves, for the reason that the air within the pump chamber is not dislodged but only compressed and expanded again by the motion of the plunger. A pump in this condition is said to be **air bound.** It is well in this case to run with the delivery pipe empty until the air is expelled and the water flows into the suction end of the pump. The waste delivery pipe is fitted with a valve and connected to the delivery pipe close to the pump. When the water flows to the pump and is discharged into the delivery pipe, the valve in the waste delivery pipe is to be closed.

AIR DISCHARGE VALVES.

53. When a check-valve is not used in the delivery pipe and the space between the suction and delivery valves is large and the delivery pipe is full of water, the pump will often refuse to start the water in the suction end, owing to compressed air being trapped between the water in the delivery pipe and the delivery valves. Air discharge valves performing similar service to the waste delivery or starting

pipes may then be used to allow the compressed air to escape and a vacuum to be created when the plunger is withdrawn from the pump chamber. In small pumps of the direct-acting type, a petcock is usually fitted for this purpose to the cover directly above the delivery valves.

GENERAL PIPING ARRANGEMENT.

54. Fig. 22 shows a good arrangement of a pump in relation to the water supply and of the pipe connections. The

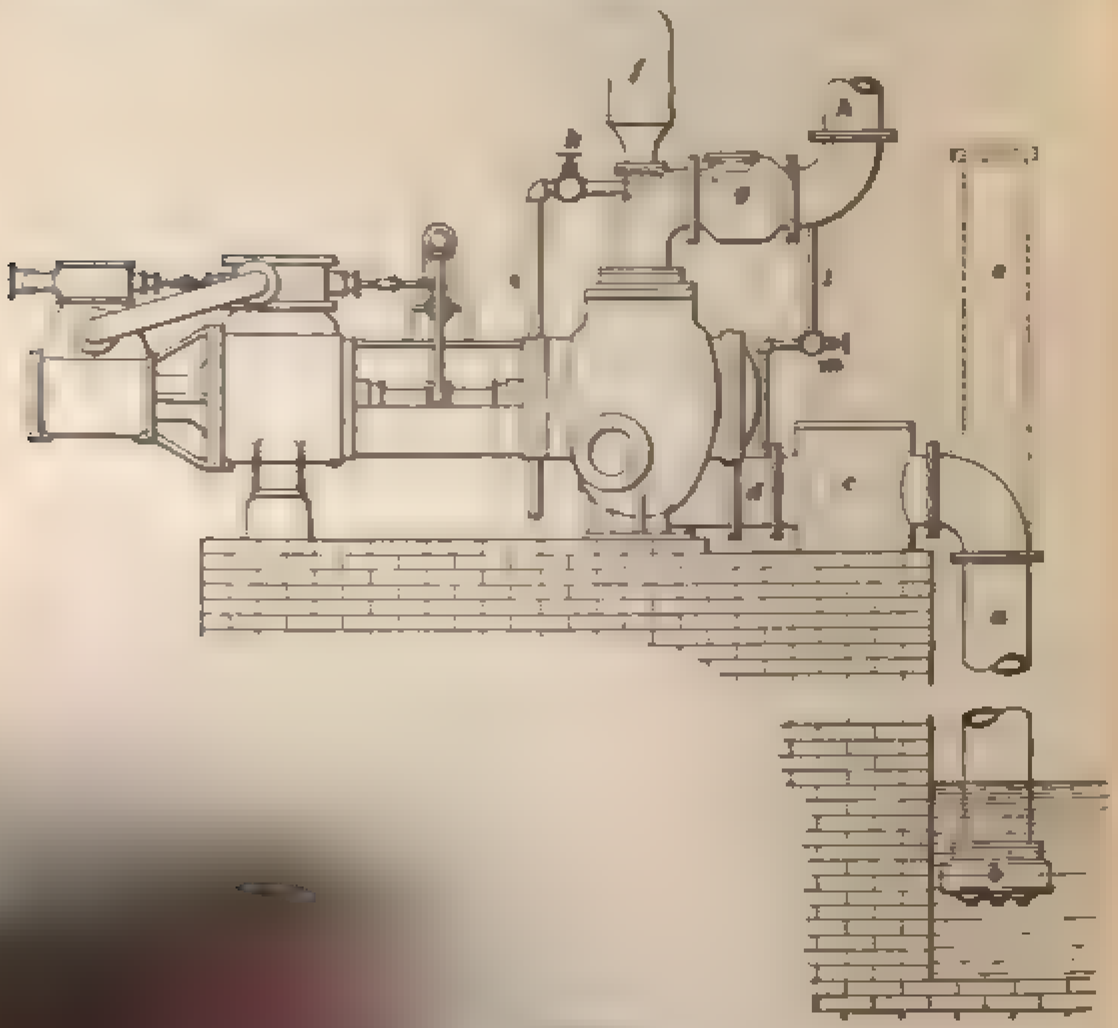


FIG. 22

fitted with the foot-valve *b* and has a
... to the pump, from which it is sepa-
... distance piece *d*. When the vertical lift is
... 10 feet, and the pump is placed close to
... ly, a suction air chamber is seldom neces-
... the lift exceeds 10 feet or when the pump is

at some distance from the water supply, a suction air chamber becomes a necessity. With a vertical suction pipe as shown, the suction air chamber may be made as shown by the dotted lines at *c*. An air chamber *f* is placed on the delivery between the delivery check-valve *g* and the delivery valves. The waste delivery or starting pipe *i* is connected to the delivery between the delivery valves and the delivery check-valve *g*. It is fitted with the valve *k*. The delivery pipe *h* is connected to the suction pipe close to the pump, in this case to the distance piece *d*, by the priming pipe *l*, which is fifted with the stop-valve *m*.

PROVISION FOR DRAINAGE.

55. Proper drain pipes and drain valves should be provided for all parts of the pump, the pipe connections, strainers, etc., in short, for all parts in which water may remain when the pump is not in use and will give trouble by freezing.

Provision for draining the suction valve deck and delivery valve deck is sometimes made by drilling a small hole through the decks; this practice, while simple and cheap, leads to a loss in efficiency, however, since some of the water is constantly flowing back into the suction chamber.

PUMP MANAGEMENT.

INTRODUCTION.

56. If a pump has been properly selected for the service and has been properly designed, built, and erected, it should perform its work without any trouble. All pumps when new are stiff and cranky in their actions, particularly direct-acting pumps. They should be run slowly for a considerable time, and many defects in their action which at first gives rise to alarm will then gradually disappear. Crank-and-flywheel pumps act more smoothly from the start, but do

not come to a proper bearing more quickly or quite as quickly as the direct-acting pump. Crank-and-flywheel pumps usually require considerable skill and study to reduce them to successful working order, as conditions arise that further disturb the lack of harmony between the flywheel and water, and it often taxes the skill of the experienced engineer to make an amicable adjustment between the two opposing forces.

57. Having reduced the pump to satisfactory operation, the attention of the operator should be directed to its maintenance at the least possible expenditure. Each item of expenditure should be separated from the whole and studied independently for the purpose of reducing it to a minimum consistent with the proper maintenance of the plant. The expenditure should at all times be regarded as the item by which interest or dividends are being earned and should not be allowed to become greater.

58. Losses in efficiency arise from wear, from loss of proper adjustments, and from the wrong timing of the various movements that control the distribution of steam, by leakages, by decreased mechanical efficiency due to lack of alinement, by accumulations of foreign matter on and in condenser tubes, suction strainer, and foot-valves, suction and delivery pipes, and in many minor directions. In many plants it is of the utmost importance that they should not be interrupted; it is then the duty of the engineer to predict all possible events that might cause an interruption and have a well-planned line of action prepared so that he may act quickly and with decision to the end of keeping his plant always at work and at the highest efficiency. This plan of action will entail considerable work, study, and, perhaps, some expense in preparation to meet possible contingencies that may never happen; nevertheless, it is well to be ready for any emergency when handling steam machinery and particularly steam pumping engines.

59. In the management of pumps it must be considered that nearly every installation has its peculiarities, some of

which are sometimes not discovered until after the machine is put in service and then perhaps require expensive additions and alterations to meet them. An exhaustive study of existing conditions and resultant conditions when the pump starts to work cannot be too strongly urged.

STARTING PUMPS.

IMPOSSIBILITY OF SPECIFIC RULES.

60. Pumps differ so much in their construction and design that it is entirely impossible to lay down specific rules that will be applicable to every pump. For this reason only *general* rules are here given, which must be modified by the pump attendant to suit every specific case.

GETTING A PUMP READY.

61. Getting Up Steam.—Considering a new steam pump, after it has been properly erected on a suitable foundation and all the pipe connections have been made, the first step in starting the pump is to get up steam in the boiler or boilers in the same manner as is done with boilers supplying steam for any other purpose.

62. Since the boilers are generally in charge of the same person that attends the pump, the general treatment of the pump and the boilers, while steam is being raised, will be considered together. After the steam piping is in place, but before it is finally connected to the pump, all valves in it should be opened wide; while steam is being raised the pistons and valves should be removed from the steam end of the pump so that there is a clear passage for the steam from the boiler to the exhaust after the steam pipe has been connected to the pump.

63. Blowing Out the Steam Piping.—The fires should be started very slowly under the boiler; all the binding

bolts throughout the boiler setting should be perfectly loose and free. If this precaution is neglected, buckstaves or cast-iron fronts will be broken by the expansion of the setting. The guy rods on iron stacks should also be slacked off; in fact, every part that will expand when the plant is started up should be liberated. Before the steaming stage is reached, large volumes of heated air will be driven through the pipes, warming them up gradually. When steam begins to rise, it should be allowed to blow through the piping and valves quite liberally, the object being to clear the piping of sand, grit, and all other foreign matter collected therein during erection. The piping having been blown out thoroughly, steam is shut off and the piping is then connected to the pump.

64. Blowing Out the Cylinder.—When the pressure in the boiler has been raised to the working pressure, the cylinder heads should be put on, still leaving the pistons and valves out of the cylinders. The stuffingboxes should be closed, which is most conveniently done by placing a piece of board between the stuffingbox and the reversed gland and then setting up the nut on the stuffingbox studs. When the gland is drawn home by a nut outside of it, a circular piece of pine board may be placed between the end of the gland and the inside of the nut in order to close the opening through which the piston rod passes. The steam may now be turned on the main steam pipe leading to the pump; by opening the throttle valve wide at short intervals, the sand and scale in the ports and other passages and spaces of the steam end can be blown out. After the cylinders have been blown out, the heads and covers should be removed, and all foreign matter blown into the corners and chambers of the cylinders should be removed by hand. The pistons, valves, cylinder heads, and other covers can now be put in place.

65. The blowing out of the pipes and cylinders after erection is often neglected or but imperfectly done, with

serious consequences to the machine; it cannot be too thoroughly done, particularly in that type of pump where the steam ports and exhaust ports are on top, for in this particular case the sand and grit are deposited in the bottom of the cylinder for the piston to ride upon. If more attention were paid to the thorough cleaning of all steam spaces, we would hear less of cylinders and pistons being cut.

66. Keying Up.—If the pump is of the crank-and-flywheel type, it should be turned a complete revolution by hand to insure that everything clears properly and that no tools or materials used during construction or erection have been left within the machine. The adjustment of all journals, pins, and bearings should then be made. With gib and key ends, it is usual to drive down the key with a soft hammer (lead hammer) until it is home, mark it, drive it back, and then tap it down to within $\frac{1}{8}$ inch of the mark. With wedge ends the wedges usually have an inclination of $1\frac{1}{2}$ inches per foot and the adjusting screw 8 threads per inch. The wedge is drawn up solid and then the adjusting screw is turned back about 20° and locked. Bolted connecting-rod ends are allowed about $\frac{1}{200}$ inch play, using liners and setting the bolts up solid. Main bearings can be adjusted best when the machine is in motion.

67. Packing Rods and Stems. — The packing of all rods and stems is the next step. If fibrous packing is used, the boxes should be filled full and the glands tightened down very moderately. The tightening of the glands can best be done when steam is on and the machine is in motion, when they should be tightened only sufficient to stop leakage and no more. When excessive tightening is required to stop leakage, the packing should be completely renewed. Some pumps are fitted with metallic packings. These packings are usually fitted up by specialists who fully guarantee them, and their directions for use should be carefully followed; in case of failure or unsatisfactory results, the makers should be consulted.

68. Oiling.—The oiling of the machinery is the next step and is a very important one. All rubbing surfaces should be provided with suitable oiling devices appropriate to the particular place and service. The quality of oil should be carefully selected to suit the velocity and pressure of the rubbing surfaces on which it is used. For use within the steam cylinder, heavy mineral oil is the only oil capable of withstanding the high temperature, and in starting up new pumps only, the best quality should be used, regardless of price. A liberal use of this oil for the first month will go far towards reducing subsequent oil bills.

69. The pumping engine, unlike many other types of engines, must often run continuously and without interruption for a month or even longer at a run. This requires that all oiling devices be so arranged that they can be supplied and adjusted while the machine is in motion. It is a good plan to provide two separate sets of oiling systems for all the principal journals, the idea being that if one fails the other can be used while the disabled one is being overhauled. All oil holes should have been filled with wooden plugs, bits of waste twisted in the hole, or some other protection, while the machine was being erected. These should now all be removed and all oil holes and oil channel thoroughly cleaned out. Bearings should be flooded with oil at first to wash out any dust or grit that may have reached the rubbing surfaces.

70. Having turned the machine by hand and inspected all locknuts, setscrews, and clamp screws, the engine may be put under steam. If provided with hand starting gear, this should be used for a sufficient number of turns to make sure that the machine is free from water that may have accumulated in the pipes or clearance spaces. All drain cocks should be wide open when starting and relief valves should be adjusted to blow at the proper pressure. If the engine is condensing, connections from the exhaust port to the condenser should be made absolutely tight. If an independent condenser is used, it should be started before

the main pump is started and a vacuum obtained in advance.

71. So far only the steam end of a large crank-and-flywheel pump has been considered. With the direct-acting single or duplex steam pump, the same general method of procedure should be followed. It may be mentioned here, incidentally, that the direct-acting pump is not so liable to an accident in starting as the crank-and-flywheel pump on account of the absence of kinetic energy stored up in a moving flywheel. This energy when given out by reason of an obstruction in the water end that prevents the free passage of water will greatly increase the pressure, especially when the obstruction occurs near the dead-center positions of the crank. The increased pressure thus produced may easily run up high enough to burst the water end.

72. Using the Dash Relief Valves.—In starting a direct-acting pump when dash relief valves are fitted, they should be closed in order to keep the pistons as far from the heads as possible, for in new installations the unexpected is likely to happen at the water end, and to prevent danger of a breakdown, as in case of a sudden lunge of the pistons, all the margin possible to keep them from striking the heads should be gained.

73. Condition of Water End When Starting.—Assuming that the plungers and plunger rods are packed and the plunger grease cups filled, the water end should be ready to start; if the machine is compound or triple-expansion, the water by-pass valves must be opened until the machine has made a sufficient number of strokes to bring the intermediate and low-pressure cylinders into action, when the by-pass valves should be closed. The suction pipe from the foot-valves to the delivery valve deck must be absolutely tight; anything short of this will cause the water end to refuse to work satisfactorily. All the suction valves and delivery valves should seat fairly and tightly. Care must be taken that there is no obstruction in the delivery pipe, such as a

closed valve, as pumps usually have sufficient margin in the driving force over the resistance to burst the water end, particularly if the momentum of a flywheel be added to it.

74. Pressure gauges should always be attached to the suction and delivery pipes, and they should be carefully watched during the process of starting, as trouble at the water end will be promptly recorded by the gauges. The lower end of the suction pipe should be kept well under water, as a slug of air taken into the pump may cause a violent jumping and in a direct-acting pump possibly a striking of the steam pistons against the heads.

75. Watching the Air Chamber.—The delivery air chamber should be carefully watched during the starting and running. This should be provided with a gauge glass showing the height of the water and extent of the pulsation. The air chamber should be charged with air when the air in the chamber is lost, as shown by the rise of the water in the gauge glass. Large pumps are usually supplied with an air charging pump that is attached to and driven by the main pump, or an arrangement of pipes and valves is sometimes improvised for this purpose. In very large pumping plants, an independent air compressor or locomotive air pump is often used for this service. A very good idea of the internal working of the pump can be obtained by placing the ear against the pump chambers; the seating of the valves can then be distinctly heard, and if there is any leak past either the suction or the delivery valves, it, too, is quite audible.

DEFECTS IN PUMPS.

SUCTION-END TROUBLES.

76. The most common causes of pump failures are leaks below the suction valves. These may be at the joints or along the suction pipe or in the pump chamber, and may be due to imperfect connections, leaky chaplets, shifted cores, blowholes, corrosion, or cracks from frost.

77. Small leaks in the suction end which are not sufficient to cause entire failure will cause the piston to jump, i. e., move suddenly, during the first part of the stroke. Leaky valves and plungers reduce the capacity of the pump; if this is the case, they should immediately be refitted and repacked. It is always best to have hot water flow to the pump by gravity; if it is necessary to lift it and the pump works with a jerky action, the lift is too high for the temperature, and one or the other must be reduced. In pumping from wells, care should be taken that the pump is near enough to the water to prevent the water falling below the maximum lift by suction.

78. If the pump pounds soon after the beginning of a stroke, when running fast, it shows that the pump chamber is not filling and that the plunger is striking the incoming water on its return stroke. A suction air chamber will help to remedy the evil. Obstructions under the suction or delivery valves will cause a very decreased output or total failure. A suction strainer or end of suction pipe becoming embedded in sand or clogged with foreign matter will cut off the supply from a pump.

79. Air pockets under the delivery valve deck, caused either by bad design or a shifting core, will very much reduce the capacity and efficiency of a pump. The effect of the air pocket is to entrap air, which is compressed to delivery-water pressure and expands again on the suction stroke. If the relative capacity of the pocket to the plunger displacement is sufficient, the entrapped air will expand to atmospheric pressure, reducing the suction lift to zero; this defect, however small, will always reduce the suction lift and is not easy to remedy; its existence should always be cause for the rejection of a pump.

80. Pounding in pumps is sometimes caused by the water lagging behind the plunger, due to the friction of a small, long, horizontal suction pipe. When suction pipes have a long horizontal run, they should be one or two sizes larger.

DELIVERY-END TROUBLES.

81. Pumps sometimes fail when the full head is resting upon the delivery valves by the air between the suction and delivery valves being expanded and compressed by the motion of the plunger. Air cocks should be provided close up under the delivery decks for discharging the air until the plungers have caught the water. If only a simple cock is fitted, it must be opened during the delivery stroke only and closed shortly before the suction stroke commences. This is to be repeated until a steady stream of water issues from it during the delivery stroke. An automatic air valve, which is simply a small spring loaded valve opening outwardly and closing automatically during the suction stroke, is preferable; this valve should be secured to its seat after a steady stream of water issues during the delivery stroke. Violent jarring and trembling of the pump arises from the delivery air chamber becoming filled with water. It should be recharged with air by means of the air-charging pump, a near-by air compressor, or by a hand air pump.

STEAM-END TROUBLES.

82. The steam end of pumps should not be taken apart needlessly, especially the steam end of direct-acting pumps with steam-thrown valves, as their action is quite complicated, and a very slight misadjustment will cause a failure. If at any time it becomes necessary to dismantle the pump, all the parts, if not already marked, should be plainly marked with steel letters or numbers, rather than with a prick punch or chisel, and suitable gauges, by which all parts can be returned to their correct relative positions, should be made, if this is deemed advisable. In many duplex pumps there are very slight differences in the two sides; for instance, the crossheads that drive the valve levers are not keyed in exactly the same position on the piston rods and the rods are not interchangeable; the pump will not run successfully if they are interchanged. In some pumps with steam-thrown valves, the valve chests are bolted to the cylinders,

and are reversible so far as fitting and bolting goes, but the auxiliary ports are not reversible and will be shut off in both valve chest and cylinder by reversing the chest. In placing the gasket between the valve chest and cylinder of pumps with steam-thrown valves, care should be taken to cut passages through the gasket for the auxiliary ports. The valve levers, pins, and all connections between the piston rod of one side of a duplex pump and the valve of the opposite side should be kept in good condition, as the failure of these parts will cause a serious accident.

83. On duplex pumps the amount of lost motion between the valve stem and the valve should be very carefully adjusted; too little lost motion will cause short stroking, while too much will allow the pistons to strike the heads. If the pistons strike the cylinder heads, the dash relief valves, if fitted, should be closed until the stroke is shortened sufficiently for the pistons to clear the heads. If the stroke becomes too short, the opposite course should be followed. If no dash relief valves are fitted, the lost motion should be made smaller in case the pistons strike the heads.

84. When a compound pump is fitted with a cross exhaust and it is seen that the pump is unable to complete its full stroke, the valve in the cross exhaust should be opened.

TESTING PUMPS FOR LEAKAGE.

85. Testing the Suction Pipe.—Leaks are the most troublesome and most frequent sources of loss of efficiency in pumping machinery. Leaks in the suction pipe or suction system affect the pump most and often cause its complete failure. These leaks can sometimes be detected by the ear, or the flame from a common tallow candle will often locate a leak in the suction by being drawn towards the hole by the air. Sometimes these leaks are very numerous, but so small that any one of them would be difficult to locate and be of small importance; at the same time, their combined effect may be sufficient to seriously affect the working of the

pump. The best way to locate these leaks, which may be at the joints or along the body of the pipe, is to stop up the inlet end of the pipe, uncover it completely, and then put a water pressure on it, say from 40 to 50 pounds per square inch. Any leaks, however small, will then be readily detected. The suction pipe should always be tested for leaks before it is covered, if laid in a trench or otherwise made inaccessible, because it must be made tight before the pump will work successfully.

86. Delivery Pipe Leaks.—Leaks in the delivery pipe, while common and at times more difficult to remedy than leaks in the suction, are plainly evident. They do not affect the action of the pump or its efficiency to any extent, the loss being exactly proportional to the magnitude of the leak.

87. Repairing Leaky Pipes.—Probably the most satisfactory method of procedure in case a leaky section of pipe is discovered is to discard it and replace it with a new one. Circumstances, however, do not always permit this to be done, and then temporary repairs should be made. The manner of making the repair obviously depends on the position and extent of the leak and calls for the exercise of judgment and some skill.

88. Small leaks in the form of pinholes in the suction pipe can generally be stopped effectually by a thick coat of red-lead putty spread over the pipe where the leaks occur. This should be covered with several layers of canvas covered on both sides with red-lead putty and wound as tightly as possible around the pipe. The canvas should then be secured by wrapping it with strong twine or annealed copper wire, put on as tightly as possible. If the suction pipe is split, it is usually well to cover the split part with a piece of sheet metal, preferably sheet lead, bent to the curvature of the pipe and put on with red-lead putty. The canvas should be wrapped over this.

A permanent repair in case of pinholes can be made by drilling out the pinhole with a twist drill and tapping out

the hole. A closely fitting threaded plug of soft steel or wrought iron is then screwed in and the end riveted over.

89. Small pinholes in delivery pipes can often be stopped up by the same means given in Art. **88** for suction pipes. If the leak is extensive, however, it will generally be necessary to use **a pipe clamp.** Such clamps may be made in a good many different ways, according to the location and extent of the leak and the facilities for repair. One of the simplest pipe clamps is shown in Fig. 23. It consists simply of a piece of sheet iron or sheet steel of sufficient width to cover the leak and bent to the form shown. A piece of sheet packing, which may be covered with red-lead putty to advantage, is placed over the leak and the pipe clamp is then placed over this and the ends drawn together by the bolt shown.

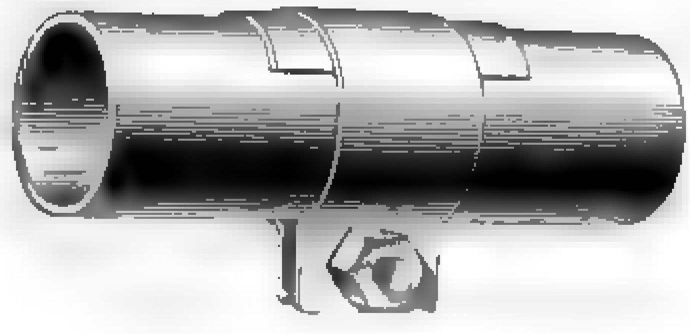


FIG. 23.

The clamp shown in Fig. 23 is only adapted for small pipes. For large pipes the clamp must be made in two halves.

90. Testing Air Chambers.—Air chambers must be absolutely tight. They are usually tested by closing all openings and then pumping air into them until the working pressure is reached, as shown by a pressure gauge. After 24 hours this gauge should show no reduction of pressure. If the air chamber does not pass this test, the leaks may be discovered by filling it with water subjected to the working pressure. If there are a number of leaks, the chamber should be condemned; if only a few small leaks exist, they can usually be effectually stopped by drilling a hole at the leak and screwing in a plug.

91. Leakage of Pistons and Plungers.—The plungers of inside-packed or center-packed plunger pumps should be

tight themselves, besides making a tight joint through the stuffingboxes, in order that water may not pass from one side to the other. The manner of testing will depend on their design, the general method of procedure being the subjecting of one side of the plunger to an air pressure or hydrostatic pressure at least equal to the working pressure. If leaks are discovered, judgment has to be used as to the manner of repairing them or whether to condemn the plunger. In some designs of inside-packed and center-packed pumps with closed hollow plungers, the weight of the plunger is so proportioned to its displacement as to relieve the stuffingboxes of nearly or quite all of its weight; it is then important that they be absolutely water-tight.

92. Leakage Past Pistons and Plungers.—With piston pumps and inside packed plunger pumps there is liable to be considerable unnoticed leakage. If it is extensive, it can be heard by placing the ear against the pump chamber. It is best with this style of pump to make regular inspections for leakage past the plunger or piston, providing suitable pipes and apparatus by means of which pressure can be put on one side of the packing or piston while the other side is exposed for inspection. With outside-packed plungers there can be no unobserved leaks past the plungers, and this is the principal reason for their use.

93. Leaks Past the Valves.—Leaks past the suction and delivery valves can readily be tested when the piston or plunger is being tested for leaks past them. The delivery and suction valves should be tested separately; the fact that the column of water in the delivery pipe does not drain out while standing is not proof that both sets of valves are tight, since either set will support the water while the other set may be leaking badly.

94. To test the suction valves for leakage, disconnect the suction pipe or take any other convenient steps that will allow the leakage to be seen. Fill the delivery pipe full of water, having removed enough delivery valves to allow the pressure to reach all the suction valves, and observe which

valves, if any, are leaking. When there is a valve in the delivery pipe, this may be shut and water pumped into the pump cylinder with a small force pump, running the pressure up to the working pressure. Care must be taken, by removing delivery valves if necessary, that the pressure reaches all the suction valves.

95. The delivery valves can be tested by filling the delivery pipe or by closing the valve in the delivery pipe and pumping water into the delivery pipe between its valve and the pump delivery valve. The pump chamber must be open so that the leaks can be seen.

SURGING OF WATER IN PIPES.

96. By surging of the water flowing through pipes is meant that its velocity of flow not only is not constant, but that the direction of flow reverses for a short period. This condition often exists in pumping machinery having very long suction or delivery pipes. It may occur either in the suction pipes or in the delivery pipes, being, however, most severe in the latter. Crank-and-flywheel pumps, owing to the variation in the piston speed between the beginning and end of the stroke, are particularly liable to cause surging, which is due entirely to an irregular delivery.

97. Duplex direct-acting pumps, owing to the uniformity of delivery and the absence of heavy weights, such as flywheels, are little liable to cause surging, and when liquids must be moved through long mains, an instance of which are the long oil pipe lines, this pump is chosen. Crank-and-flywheel pumps forcing water through very high delivery pipes, as occurs in mine work, are seriously affected by the surging of the water. Air chambers do not help matters, but probably aggravate them by forming an elastic cushion for the column of water to rebound from. The effect of surging water is to vary the pressure on the pump and mains, sometimes from zero to twice the pressure due to the vertical height, resulting in broken pump chambers,

pipes, and not infrequently in damage to the working parts of the pump, for the actual resistance to these shocks is not met until they arrive at the flywheel rim.

98. The remedying of surging is not easy of attainment. Air chambers placed along the delivery pipe at intervals are employed occasionally, the aim being to break up the vibrations of the surging water and get them out of step or out of harmony with the motion of the pump. Alleviators are sometimes used in place of air chambers to relieve the shock, and not being so elastic do not encourage surging to the extent that air chambers do. When for economical reasons it is desired to use the crank-and-flywheel pump, the variations in pressure and the liability to surging can be very much reduced by using the three-throw crank with the pins set at 120° from one another.

99. Surging in long suction pipes is liable to occur especially when the water flows to the pump by gravity; this is not so difficult to overcome or so serious in its effects as surging in the delivery pipe, for the reason that the direction of the force resulting from the surge is through the pump valves and into the delivery, or in the natural direction of the water, while the shock due to surging in the delivery pipe comes against the valves and must be withstood by the machinery.

100. To prevent shocks due to surging reaching the machinery, a liberal sized air chamber is needed on the suction main near the pump, and in addition spring-loaded relief valves may also be fitted to the main. These relief valves simply limit the pressure due to an unusually heavy surge that cannot be taken care of by the air chamber.

PUMPING A MIXTURE OF WATER AND AIR.

101. In mine and artesian-well work, large quantities of air are often mixed with the water, due to local disturbances in the source of supply, such as water discharging into it in the form of spray. When such a mixture of air and water

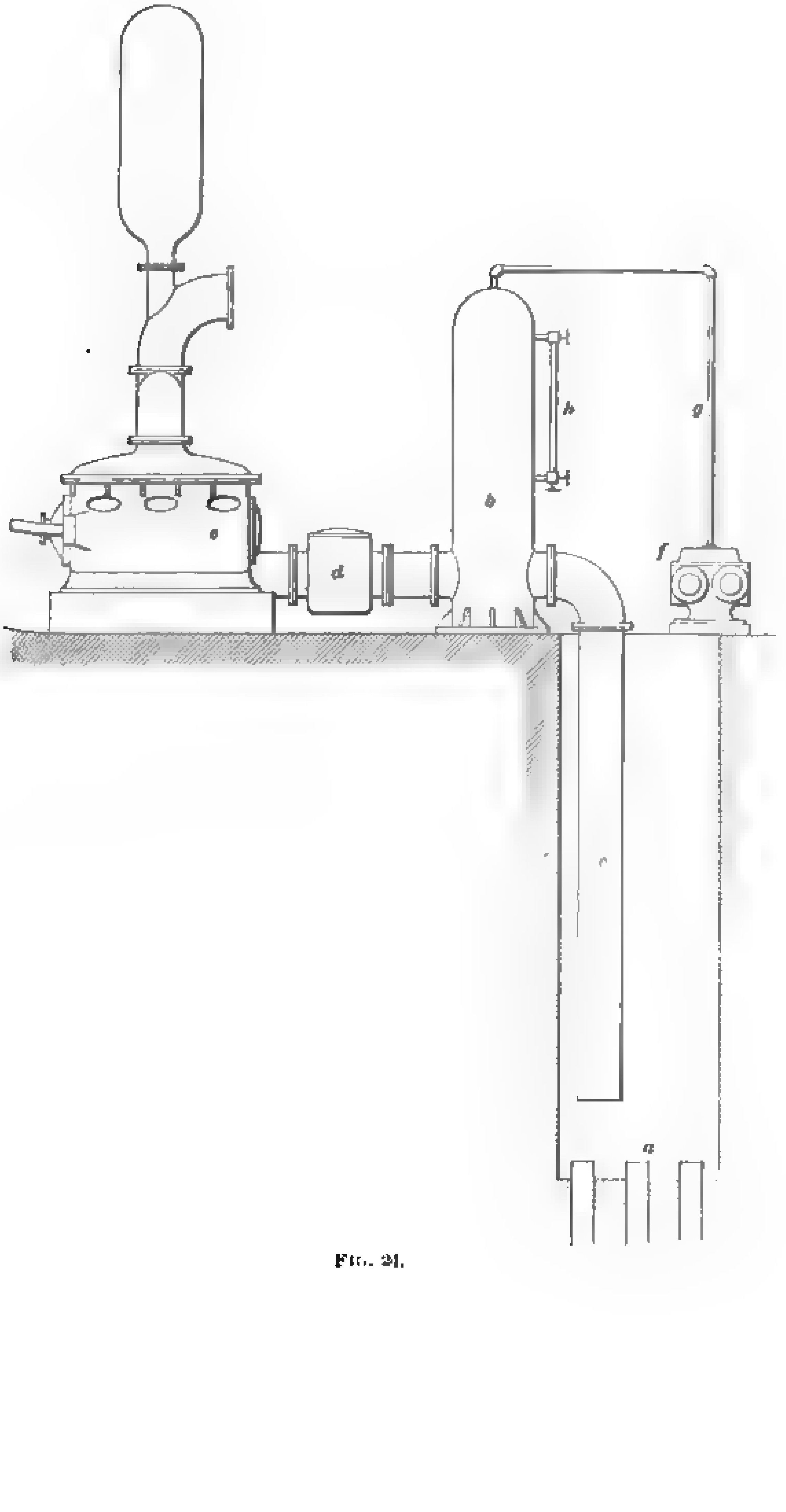


Fig. 24.

is pumped, the pump will have a jerky motion, that is, instead of moving steadily it will move in jumps, and in the case of direct-acting pumps there is danger of striking the cylinder heads. Besides, on account of the uneven discharge there will be violent disturbances in the delivery pipe. The only effectual remedy is to remove the air before it arrives at the pump.

102. Fig. 24 shows the installation of a pump taking its water from an artesian well *a*, the water being highly charged with air and gas. A large suction air chamber *b* is put into the suction pipe *c*; the water passes through the strainer *d* to the pump *e*. A vacuum pump *f* is connected by the pipe *g* to the top of the air chamber and not only maintains a vacuum in the chamber, but draws the air and gas out of the water in the chamber and before it reaches the pump. The gauge glass *h* not only shows the height of water in the air chamber, but also allows the bubbles of air and gas rising through the water to be seen. The vacuum pump is simply an ordinary steam pump pumping air instead of water; it is running constantly and its speed is regulated to suit the height of the water in the air chamber.

SETTING THE VALVES OF DUPLEX STEAM PUMPS.

103. The steam valves of duplex pumps have no outside or inside lap, consequently when in their central position they just cover the steam ports leading to opposite ends of the cylinders. With all these valves a certain amount of lost motion is provided between the jam nuts and the valve. This lost motion in small pumps is within the steam chest, while in large pumps it is outside and may be adjusted while the pump is in motion. The first move in the process of setting the valves of duplex pumps is to remove the steam-chest bonnets and to place the pistons in their mid-stroke position. To do this, open the drip cocks and move each piston by prying on the crosshead, but never on the valve lever, until it comes into contact with the cylinder head.

Make a mark on the piston rod at the steam-end stuffingbox gland. Move each piston back until it strikes the opposite head, and then make a second mark on the piston rod. Half way between the first and second mark make a third one. Then, if each piston is again moved until the last mark coincides with the face of the gland, the pistons will be exactly at their mid-stroke position. After placing the pistons in their mid-position, set the valves central over the ports. Adjust the locknuts so as to allow about $\frac{3}{16}$ inch lost motion on each side. The best way of testing the equal division of the lost motion is to move each valve each way until it strikes the nut or nuts and see if the port openings are equal. When the port opening has been equalized, the valves are set. The valve motion need not be and should not be disturbed while setting the valves. Too much lost motion will tend to lengthen the stroke and may cause the piston to strike the cylinder heads, while on the other hand when there is not enough lost motion, the stroke will be perceptibly shortened. The proper amount of lost motion to give a certain length of stroke can only be found by trial for each particular pump.

104. If only one valve of a duplex pump is to be set, bear in mind that it is operated by the piston of the opposite pump. Place that piston in its mid-position and then set the valve as previously explained.

PUMPS.

(PART 3.)

CALCULATIONS RELATING TO PUMPS.

DISPLACEMENT.

1. The **displacement** of a pump for a single stroke is the volume of water that would be displaced (that is, driven out of the cylinder) by the piston or plunger during that stroke.

In calculating the displacement of a pump in a given time, care must be taken to consider the number of strokes during which water is discharged. Thus, for a single-acting pump, water is discharged only when the piston moves in one direction; and with the double-acting pump the number of strokes during which discharge occurs is equal to the total number of strokes that the piston makes. With a duplex double-acting pump, it is customary when giving the number of strokes per minute to refer only to the number of strokes made by one piston, which, obviously, is only one-half the total number of strokes made. As practice varies, however, among engineers in this respect, it is best to find out in each case, by inquiry, whether the number of strokes of one piston or of both pistons in a given time is meant when the number of strokes is given. In the case of a crank-driven pump, for a single single-acting pump the strokes will be equal to the revolutions of the crank; for a single

double-acting and a double single-acting crank-driven pump the strokes will equal twice the number of revolutions; for a triplex single-acting crank-driven pump the strokes will equal three times the number of revolutions; and for a triplex double-acting pump, six times the number of revolutions.

2. The displacement of a pump in a minute in cubic feet, gallons, or pounds is given by the following rule:

Rule 1.—*Multiply the length of stroke in inches by the mean effective area of the pump piston or plunger in square inches and the number of strokes per minute. The product is the displacement in cubic inches. To reduce the displacement to pounds, multiply by the weight of a cubic inch of the liquid pumped; to reduce to cubic feet, divide the displacement by 1,728; to reduce to Winchester gallons, divide the displacement by 231; to reduce to English imperial gallons, divide the displacement by 277.27.*

Or,

$$D_p = L\,A\,N\,S,$$

$$D_c = \frac{L\,A\,N}{1{,}728},$$

$$D_{ag} = \frac{L\,A\,N}{231},$$

$$D_{eg} = \frac{L\,A\,N}{277.27},$$

where

L = length of stroke in inches;
A = area of piston or plunger in square inches;
N = number of delivery strokes per minute;
S = weight in pounds of a cubic inch of the liquid,
D_p = displacement in pounds per minute;
D_c = displacement in cubic feet per minute;
D_{ag} = displacement in Winchester gallons per minute;
D_{eg} = displacement in English imperial gallons per minute.

3. Attention is here called to the fact that there are three different gallons in use, of which the Winchester, or wine, gallon, measuring 231 cubic inches, is most commonly

used in America. In Great Britain and her colonies the imperial gallon, holding 277.27 cubic inches, is largely used as a measure. In most English-speaking countries the beer or ale gallon of 282 cubic inches capacity is also used, but almost exclusively for measuring the liquids mentioned. When the discharge of a pump is given in gallons in the United States of America, it is always understood, unless distinctly stated otherwise, to be in gallons measuring 231 cubic inches.

4. The **mean effective area** of the piston or plunger is equal to the area corresponding to the diameter only in case of outside-packed plunger pumps. In case of inside-packed and center-packed plunger pumps and double-acting piston pumps, the mean effective area is found by dividing the sum of the piston or plunger area and the same area diminished by the area of the piston rod by 2. Thus, in a double-acting inside-packed plunger pump having a plunger 10 inches in diameter and a 2-inch piston rod, the mean effective area is $\frac{10^2 \times .7854 + (10^2 \times .7854 - 2^2 \times .7854)}{2}$ $= 76.97$ square inches. In case of a single-acting piston pump, which generally is a lift pump, the effective area will be the area of the piston diminished by the area of the piston rod, since the piston rod is on the delivery side. In case of a differential pump having the plunger areas in the ratio of 1 to 2, the area of the smaller plunger is the effective area. In rough, approximate calculations of displacement, the correction for the area of the piston rod or plunger rod need not be made, and then the area of the piston or plunger is considered as the effective area. When the displacement requires to be accurately known, however, the mean effective area should be used.

EXAMPLE 1.—A single-acting plunger pump is driven by a crank whose radius is 8 inches and whose number of revolutions is 30 per minute. If the plunger is 6 inches in diameter, what is the displacement in cubic feet per minute?

SOLUTION.—The number of discharging strokes of the plunger is equal to the number of revolutions of the crank, or 30 per minute; the

length of the stroke is $8 \times 2 = 16$ inches. The area of the plunger is $6^2 \times .7854 = 28.27$ square inches. Applying rule **1**, we have

$$D_c = \frac{16 \times 28.27 \times 30}{1,728} = 7.85 \text{ cu. ft. per min. Ans.}$$

EXAMPLE 2.—A center-packed double-acting duplex pump has plungers 24 inches diameter with 4-inch plunger rods. Each plunger makes 30 strokes per minute, the length of stroke being 32 inches. What is the displacement in American (Winchester) gallons per minute?

SOLUTION —The mean effective area of the plungers is

$$\frac{24^2 \times .7854 + (24^2 \times .7854 - 4^2 \times .7854)}{2} = 446.1 \text{ square inches.}$$

Since the pump is duplex, there are $30 \times 2 = 60$ strokes per minute. Applying rule **1**, we get

$$D_{ag} = \frac{32 \times 446.1 \times 60}{231} = 3,707.8 \text{ gal. per min. Ans.}$$

DISCHARGE.

5. The **theoretical discharge** of a pump is equal to the *displacement.*

6. The **actual discharge** is generally less than the displacement, owing to leakage past the valves and piston and also to the return of water through the valves while they are in the act of closing.

SLIP.

7 The difference between the displacement and the actual discharge, expressed as a percentage of the displacement, is called the **slip** of a pump.

8. Negative Slip.—When the column of water in the suction and discharge pipes of a pump is long and the lift moderate, the energy imparted by the piston during the discharge stroke may be sufficient to keep the column in motion during all or a part of the return stroke. Under these conditions, the actual discharge may be greater than the displacement, and the slip is then said to be *negative.*

Rule 2.—*To calculate the slip of a pump, find the difference between the displacement and the actual discharge, multiply it by 100, and divide the product by the displacement. The quotient will be the slip expressed in per cent. of the displacement.*

EXAMPLE.—A single-acting plunger pump with a plunger 8 inches in diameter and 36 inches stroke discharges 33.5 cubic feet of water per minute when making 35 discharging strokes. What is the slip?

SOLUTION.—By rule 1, the displacement is

$$\frac{36 \times 8^2 \times .7854 \times 35}{1,728} = 36.652 \text{ cubic feet per minute.}$$

By rule 2, the slip is

$$\frac{(36.652 - 33.5) \times 100}{36.652} = 8.6 \text{ per cent., nearly. Ans.}$$

WORK DONE BY A PUMP.

9. The **useful work** in foot-pounds done by a pump is the product of the water raised in pounds multiplied by the vertical distance in feet from the surface of the water in the well or supply reservoir to the outflow end of the discharge pipe.

10. The **actual work** is always greater than the useful work. Force is required to overcome the friction of the piston or plunger in the cylinder or stuffingbox, and considerable force is also required to overcome the friction of the water in its passage through the pipes and the valves and passages of the pump. Some force must also be expended in giving the water the velocity it has when it leaves the discharge pipe.

The theoretical force required to drive the piston is equal to its area multiplied by the pressure due to a head equal to the vertical distance from the surface of the water in the well to the outlet of the discharge pipe. The actual force can be found by the aid of a pressure gauge or indicator attached to the pump cylinder, which will give the actual pressure on the piston in pounds per square inch.

According to the principles of hydraulics and the flow of water through pipes, it is evident that the power required to overcome the frictional resistance of the water will be reduced by making the pipes large and direct and the passages through the valves and pump of ample size and as direct as possible, so as to avoid loss from sudden change of direction of flow.

HORSEPOWER OF PUMPS.

11. The indicated horsepower developed in the cylinder or cylinders of a steam-driven or compressed-air-driven pump is found in exactly the same manner as with a steam engine and from the same data. The horsepower usefully expended is given by dividing the useful work done by the pump in 1 minute by 33,000. The ratio of the usefully expended horsepower to the indicated horsepower is an indication of the mechanical efficiency of the pumping apparatus considered as a whole.

12. It is often required to estimate what horsepower will be required to pump a given quantity of water per minute to a given elevation or against a given pressure. This problem can only be solved approximately by a general rule, there being a number of variable factors entering into the solution, such as the general run and length of the piping, the design of the water end, the degree of workmanship, etc. The influence of some of these factors cannot be determined beforehand with any great degree of accuracy, and for that reason any general rule for estimating the required horsepower must be based on a low mechanical efficiency of the pumping apparatus in order to leave an ample margin for safety.

13. In estimating upon the probable horsepower, it is occasionally necessary to convert a given pressure into a head of water in feet that will exert the same pressure. This can be readily done by multiplying the given pressure by 2.3.

14. If the volume of water to be discharged per minute is given in cubic feet and the vertical height from the suction level to the discharge level in feet is known, the foot-pounds of work to be done is 62.5 × volume × vertical height, taking the weight of a cubic foot of water as 62.5 pounds. Consequently, the theoretical horsepower is

$$\frac{62.5 \times \text{volume} \times \text{vertical height}}{33{,}000},$$

or

$$\frac{\text{foot-pounds of work to be done}}{33{,}000}.$$

Assuming an efficiency of 70 per cent., the actual horsepower will be

$$\frac{100 \times \text{foot-pounds of work to be done}}{70 \times 33{,}000}$$

$$= \frac{\text{foot-pounds of work to be done}}{23{,}100}$$

Hence the following rule:

Rule 3.—*To estimate the probable horsepower required to drive a pump, multiply the weight to be discharged per minute by the vertical lift and divide by 23,100.*

Or, $$H_e = \frac{WL}{23{,}100},$$

where H_e = estimated horsepower;
W = weight of water discharged per minute in pounds;
L = vertical lift in feet.

EXAMPLE.—About what horsepower will be required to discharge 350 gallons of water per minute, the total lift being 320 feet?

SOLUTION.—The weight of the Winchester, or ordinary American, gallon is 8.34 pounds, nearly. Hence, the weight of water to be pumped per minute is $350 \times 8.34 = 2{,}919$ pounds.

Applying rule **3**, we get

$$H_e = \frac{2{,}919 \times 320}{23{,}100} = 40 \text{ H. P., about.} \quad \text{Ans.}$$

15. When the weight of water to be discharged per minute and the pressure against which it is to be pumped are

[illegible] ce is weight × pressure [illegible] an efficiency of 70 per cent., the [illegible] required is

$$\frac{[illegible]\ \text{weight} \times \text{pressure} \times [illegible]}{[illegible]} = \frac{\text{weight} \times \text{pressure}}{10,043}.$$

Rule 4.—*[illegible] horsepower, multiply the [illegible] per minute by the pressure [illegible].*

Or,
$$H = \frac{WP}{10,043},$$

where
P = pressure per square inch;
W = weight of water per minute.

In rules 5, 6, 7, and 8 the letters have the same meaning as in rules 3 and 4.

EXAMPLE.—A pump is to pump 400 cubic feet of water per hour against a pressure of 90 pounds per square inch. Estimate the probable horsepower required.

SOLUTION.—Reducing the volume per hour to pounds per minute, we have

$$\frac{400 \times 62.5}{60} = 416.7, \text{ say } 417 \text{ pounds.}$$

Applying rule 4, we get

$$H = \frac{417 \times 90}{10,043} = 3.7 \text{ H. P., about. Ans.}$$

16. Rule 5.—*[illegible] lift with a given [illegible] 23,100 and divide by [illegible] per minute.*

$$l = \frac{23,100\ H}{W}.$$

[illegible] by a 10-horsepower engine is to discharge [illegible] per minute. How high may this water be lifted, [illegible]

[illegible] rule 5, we get

$$l = \frac{23,100 \times 10}{2,000} = 115.5 \text{ ft. Ans.}$$

17. Rule 6.—*To estimate the probable discharge in pounds per minute, divide 23,100 times the horsepower by the vertical lift in feet.*

Or, $$W = \frac{23,100\, H_e}{L}.$$

EXAMPLE.—How many pounds of water per minute, approximately, can a pump driven by a 25-horsepower engine discharge at a height of 42 feet?

SOLUTION.—Applying rule **6**, we get

$$W = \frac{23,100 \times 25}{42} = 13,750 \text{ lb., about. Ans.}$$

18. Rule 7.—*To estimate the pressure that can be pumped against, multiply the horsepower by 10,043 and divide by the weight to be pumped per minute.*

Or, $$P = \frac{10,043\, H_e}{W}.$$

EXAMPLE.—A 9-horsepower pump is to discharge 6,000 pounds of water per minute. Estimate against what pressure this can be discharged.

SOLUTION.—Applying rule **7**, we get

$$P = \frac{10,043 \times 9}{6,000} = 15 \text{ lb. per sq. in. Ans.}$$

19. Rule 8.—*To estimate the probable discharge in pounds per minute, multiply the horsepower by 10,043 and divide by the pressure to be pumped against.*

Or, $$W = \frac{10,043\, H_e}{P}.$$

EXAMPLE.—How much water may a pump be estimated to discharge in Winchester gallons per minute when the pump is 40-horsepower and pumps against a pressure of 100 pounds per square inch?

SOLUTION.—Applying rule **8**, we get

$$W = \frac{10,043 \times 40}{100} = 4,017.2 \text{ pounds per minute.}$$

Since a Winchester gallon weighs 8.34 pounds, we have

$$\frac{4,017.2}{8.34} = 481.7 \text{ gal. per min. Ans.}$$

SIZE OF PISTONS AND PLUNGERS.

20. Before the size of a piston or plunger for the water end of a pump can be determined, the quantity of water to be pumped and the piston speed must be known. The piston speed is the number of feet traveled per minute by the plunger when *discharging* water; that is, it equals the length of the stroke in feet multiplied by the number of *working* strokes per minute. If the pump is double-acting, the number of working strokes is the same as the total number of plunger strokes, both forward and back; if single-acting, half that number. If the pump is duplex, it is advisable to consider only one side in determining the size of plunger or piston, designing it to suit one-half the total quantity of water to be delivered. In direct-acting steam pumps the piston speed is generally about 100 feet; at least it is customary to design them on this assumption, and then to run the pump faster or slower to suit the required delivery, opening or closing the throttle valve to vary the speed of the pump.

21. Knowing the actual volume of water to be discharged in 1 minute in cubic feet, the plunger or piston area in square feet will be $\frac{\text{discharge}}{\text{piston speed}}$, theoretically. But in practice the diameter of the plunger or piston is given in inches, hence the area should be expressed in square inches.

Then, $$\text{area} = \frac{\text{discharge in cubic feet} \times 144}{\text{piston speed in feet}},$$

and the corresponding diameter in inches will be

$$\sqrt{\frac{\text{discharge} \times 144}{.7854 \times \text{piston speed}}}.$$

22. Since there is always more or less slip of the water, it is usual to design the pump on the assumption that it must pump 1.25 times the actual amount of water. On this assumption the plunger or piston diameter in inches will be

$$\sqrt{\frac{\text{discharge} \times 1.25 \times 144}{.7854 \times \text{piston speed}}},$$

or
$$\sqrt{\frac{229 \times \text{discharge}}{\text{piston speed}}}.$$

Rule 9.—*To find the diameter of a plunger or piston in inches, multiply the discharge in cubic feet per minute by 229 and divide the product by the piston speed in feet per minute. Extract the square root of the quotient.*

Or,
$$d = \sqrt{\frac{229\, D}{S}},$$

where d = diameter of piston or plunger in inches;
D = actual discharge in cubic feet per minute;
S = piston speed.

When the discharge is given in pounds, gallons, or any other unit of volume, it should be reduced to cubic feet before applying rule **9**.

EXAMPLE.—What should be the diameter of a pump plunger required to discharge 130 Winchester gallons per minute, the speed of the plunger being 90 feet per minute?

SOLUTION.—Reducing the gallons to cubic feet, we have

$$\frac{130 \times 231}{1{,}728} = 17.378 \text{ cubic feet per minute.}$$

Applying rule **9**, we get

$$d = \sqrt{\frac{229 \times 17.378}{90}} = 6.65 \text{ in., nearly. Ans.}$$

23. Rule 10.—*To estimate the probable discharge in cubic feet, square the diameter of the plunger or piston in inches and multiply by the piston speed. Divide the product by 229.*

Or,
$$D = \frac{d^2 S}{229}.$$

EXAMPLE.—How many pounds of water per hour may a duplex double-acting pump be expected to discharge when the diameter of the plungers is 6 inches, the length of stroke 24 inches, and each plunger makes 40 strokes per minute?

SOLUTION.—The piston speed is $\frac{24}{12} \times 40 = 80$ feet per minute. The probable discharge per minute in cubic feet, by rule **10**, is

$$D = \frac{6^2 \times 80}{229};$$

$$\text{per hour, } D = \frac{6^2 \times 80 \times 60}{229}.$$

The discharge in pounds per hour, taking 62.5 pounds as the weight of a cubic foot of water, is

$$D = \frac{6^2 \times 80 \times 60 \times 62.5}{229}$$

for one side of the pump. For both sides,

$$D = \frac{6^2 \times 80 \times 60 \times 62.5 \times 2}{229} = 94{,}323 \text{ lb.} \quad \text{Ans.}$$

In applying rule **10** it is to be observed that the result will be less than given by multiplying the displacement per stroke by the number of strokes per minute, as called for by rule **1**. The reason for this discrepancy is obvious; rule **1** gives the theoretical discharge, while rule **10** gives about what the pump may actually be expected to discharge.

24. In direct-acting steam pumps the normal piston speed is generally 100 feet per minute. On this basis the probable discharge in cubic feet, by rule **10**, is $D = \frac{d^2 \times 100}{229}$, and in Winchester gallons the discharge is $\frac{d^2 \times 100 \times 1{,}728}{231 \times 229}$ $= 3.26\, d^2$.

Rule 11.—*To roughly approximate the probable normal discharge of a direct-acting steam pump in gallons, multiply the square of the diameter of the plunger or piston by 3.26.*

Or, $$D_g = 3.26\, d^2,$$

where D_g = discharge in gallons per minute;
d = diameter of piston or plunger in inches.

25. The theoretical normal discharge in gallons per minute at a piston speed of 100 feet is given almost exactly by multiplying the square of the diameter of the plunger or piston by 4. For a duplex pump the discharge is double that given by rule **11**.

EXAMPLE.—What may the discharge in gallons of a duplex pump with 6-inch plungers be roughly estimated at?

SOLUTION.—Applying rule **11**, we get $D_g = 3.26 \times 6^2$ for each side, or

$$D_g = 3.26 \times 6^2 \times 2 = 235 \text{ gal. per min.} \quad \text{Ans.}$$

26. Having determined the proper plunger or piston diameter for the chosen piston speed, it remains to choose either a length of stroke or a number of strokes in order to determine either the number of strokes or the length of stroke. The ratio of the diameter to the length of stroke varies between very wide limits in practice, being as low as 1 : 1 and as high as 1 : 5. Obviously, the greater the ratio, the fewer times will the valves have to be moved, hence a great ratio is generally chosen for pumps that have to run continuously in a hard, rough service. Having chosen a length of stroke, use the following rule:

Rule 12.—*To find the number of strokes, divide the piston speed in feet by the chosen length of stroke in feet. To find the length of stroke in feet, divide the piston speed in feet by the number of delivery strokes per minute.*

Or, $$N = \frac{P}{L},$$

and $$L = \frac{P}{N},$$

where $P =$ piston speed;
$N =$ number of delivery strokes per minute;
$L =$ length of stroke in feet.

EXAMPLE.—What should be the length of stroke for a piston speed of 100 feet if the number of strokes per minute is 40?

SOLUTION.—Applying rule **12**, we get

$$L = \tfrac{100}{40} = 2.5 \text{ ft.},$$

or $$2.5 \times 12 = 30 \text{ in. Ans.}$$

SIZE OF STEAM END.

27. In a direct-acting steam pump the size of the steam-end cylinder depends on two factors, which are the steam pressure available and the resistance against which the pump is to force the water. The stroke of the steam piston and water piston obviously are the same, both being rigidly connected to the same rod.

28. The forces acting on the steam piston and water piston are equal when the area of the steam piston × the steam pressure = area of water piston × pressure pumped against. But in order that there may be an ample margin to overcome the frictional resistances, which make the actual resistance to the motion of the water piston greater and lessen the force that impels the steam piston forwards, the area of the steam piston should be, at least, 40 per cent. in excess of its theoretical area. On this basis, we have area of steam piston

$$= \frac{1.4 \times \text{area of water piston} \times \text{pressure}}{\text{steam pressure}},$$

and diameter of steam piston

$$= \sqrt{\frac{1.4 \times \text{area of water piston} \times \text{pressure}}{.7854 \times \text{steam pressure}}},$$

or diameter of steam piston

$$= \sqrt{\frac{1.8 \times \text{area of water piston} \times \text{pressure}}{\text{steam pressure}}}.$$

Rule 18. [illegible] diameter of the steam [illegible] multiply 1.8 times the [illegible] by the pressure in [illegible] against; divide by the [illegible] the square root of the [illegible]

[illegible]

[illegible] piston in inches;

[illegible]

EXAMPLE.—[illegible] diameter of the steam piston [illegible] diameter the available steam pressure [illegible] the water to be pumped against [illegible] inch?

SOLUTION.—The area of the plunger is $8^2 \times .7854 = 50.27$ square inches. Applying now rule **13**, we get

$$d_m = \sqrt{\frac{1.8 \times 50.27 \times 200}{75}} = 15.5 \text{ in.} \quad \text{Ans.}$$

29. It is to be observed that rule **13** applies equally well to steam- and air-driven pumps. It can also be applied to simple pumps of the crank-and-flywheel type using steam expansively. In the latter case, the mean effective pressure throughout the stroke must be taken as the available steam pressure. Rule **13** is especially useful in deciding whether a given pump will pump against a known pressure with the existing sizes of steam and water pistons. It will also be found very useful in selecting a pump for a given service from the catalogues of manufacturers.

30. In boiler-feed pumps the steam pressure available and the pressure pumped against are practically equal, so that it might be expected that the area of the steam piston would be made about 40 per cent. larger than the area of the water piston. In actual practice it is found, however, that pump manufacturers prefer to make the steam piston about 3 times the area of the water piston in very small pumps and about twice the area of the water piston in large pumps. The steam piston of boiler-feed pumps is made so largely in excess of what it really needs to be merely as a matter of safety; its large size simply tends to insure a prompt starting of the pump under almost all conditions likely to arise in practice.

31. The steam end of direct-acting pumps and of direct-connected crank-and-flywheel pumps, where the steam and water pistons move together, is rarely proportioned on the basis of horsepower required to do the work, it being much easier to calculate the size of the steam end by rule **13**.

32. When a power pump is driven by a separate steam engine, through the intervention of belting or gearing, the engine itself is generally selected on the basis of horsepower

[illegible]

THE DUTY OF STEAM PUMPS.

DEFINITION

The [illegible] by a pump and a [illegible] used to do the [illegible] the **duty** [illegible]

[illegible] a day, the pump will [illegible] certain height and thus perform a definite amount of work. To do this work, the pump has received from the boilers a certain number of heat units or a number of pounds of steam, or, if the boilers are included as a part of the system, the work has been accomplished by consuming a certain amount of coal. The pump [illegible] credited with the work it has performed in the stated time [illegible] charged with the number of heat units, pounds of [illegible] it has used in doing the work. It is [illegible] the pump or pumping engine is [illegible] the work performed to the steam [illegible] coal burned. Thus, if one pump does [illegible] foot-pounds of work with a coal consumption of [illegible] and another under the same conditions does [illegible] foot-pounds and consumes only 60 pounds of coal, [illegible] evidently the more economical, since the ratio of [illegible] consumption is larger, being (36,000,000 ÷ 60) [illegible] foot-pounds of work with a coal consumption [illegible] 100 pounds.

DUTY BASED ON COAL CONSUMPTION.

34. When the duty is based on the consumption of coal, it is customary to assume 100 pounds of coal as the fuel unit; that is, the duty is defined as the number of foot-pounds of work performed for each 100 pounds of coal burned. Then,

$$\text{Duty} = \text{foot-pounds of work} \div \frac{\text{pounds of coal}}{100},$$

or,

$$\text{Duty} = \frac{\text{foot-pounds of work} \times 100}{\text{pounds of coal}}.$$

Rule 14.—*To find the duty of a pump per 100 pounds of coal, multiply together 100, the weight of water pumped in a given time in pounds, and the vertical distance in feet from the level of supply to the level of discharge. Divide the product by the coal consumption in the same time in pounds.*

Or,

$$D = \frac{100\, w\, h}{W},$$

where D = duty;
w = weight of water in pounds;
W = weight of coal in pounds;
h = vertical lift in feet.

EXAMPLE.—A pump raises 130,000 pounds of water 60 feet and the operation requires the combustion of 25 pounds of coal. What is the duty?

SOLUTION.—Applying rule **14**, we have

$$D = \frac{100 \times 130{,}000 \times 60}{25} = 31{,}200{,}000 \text{ ft.-lb. per 100 lb. of coal.} \quad \text{Ans.}$$

35. The duty based on the coal consumption is of practical value, as it gives an idea of the coal required by a pump of a given type for the performance of a stated quantity of work. It is clear, however, that if a comparison of the merits of two pumps is to be made, the coal must be of the same quality in each case. Further, the boilers supplying steam to the pumps should be of the same type or at least have the same evaporative capacity. This is a point of great importance. One hundred pounds of good bituminous or anthracite coal may, under favorable conditions, evaporate

1,000 to 1,100 pounds of water; that is, furnish that number of pounds of steam to the pump. In many cases, however, the 100 pounds of coal, if of inferior quality and burned under a poor boiler, will not furnish the pump more than 450 to 600 pounds of steam. Under such conditions the duty of the pump based on the coal consumption would not be a fair indication of its efficiency and would not serve as a satisfactory basis for comparing it with other pumps.

DUTY BASED ON STEAM CONSUMPTION.

36. In order to avoid the drawbacks incidental to basing the duty of pump on the coal consumption, it is the custom of some pump makers to specify that the coal consumption shall be estimated on the supposition that a pound of coal evaporates 10 pounds of water, or, in other words, furnishes 10 pounds of steam to the pump. To make this clear, suppose that in a duty trial 32,000 pounds of steam were used by the pump; the duty of the pump would be calculated on the assumption that the coal consumption was 32,000 ÷ 10 = 3,200 pounds, though 5,000 pounds might actually have been used. If 1 pound of coal is assumed to furnish 10 pounds of steam, 100 pounds of coal will furnish 1,000 pounds of steam; hence, the duty based on steam consumption may be defined as the number of foot-pounds of work done by the pump per 1,000 pounds of dry steam supplied it. Then,

$$\text{Duty} = \frac{\text{foot-pounds of work} \times 1{,}000}{\text{pounds of steam}}.$$

Rule 15.—*To find the duty of a pump per 1,000 pounds of dry steam, multiply together the weight of water pumped in pounds, the vertical distance in feet from the level of supply to the level of discharge, and 1,000. Divide by the weight of steam supplied in pounds.*

Or,
$$D = \frac{1{,}000\, w h}{S},$$

where S = weight of dry steam supplied in pounds and the other letters have the same meaning as in rule **14**.

EXAMPLE.—A pump lifted 7,920,000 pounds of water 126 feet with 8,100 pounds of steam. What is its duty?

SOLUTION.—Applying rule **15**, we get

$$D = \frac{1,000 \times 7,920,000 \times 126}{8,100}$$

$= 123,200,000$ ft.-lb. of work per 1,000 lb. of dry steam. Ans.

37. The basis of 1,000 pounds of dry steam is more scientific and better adapted for duty trials than that of 100 pounds of coal, but it is open, nevertheless, to objections. Not only is it difficult to determine the exact weight of dry steam entering the pump, but also 1,000 pounds of steam at 160 pounds pressure will do more work in the cylinder than 1,000 pounds of steam at 60 pounds pressure. If scientific accuracy is sought, the pressure of the steam should be specified in addition to the weight.

DUTY BASED ON HEAT UNITS SUPPLIED.

38. On account of the objections to the basis of comparison then used, a committee of The American Society of Mechanical Engineers in 1891 recommended a new basis for the estimation of duty. Whether the furnace consumes 100 or 200 pounds of coal, whether the steam is at 60 or 160 pounds pressure, wet or dry, the steam cylinders of the pump or pumping engine receive in a given time a definite number of British thermal units. We have seen that if each of two pumps is allowed 100 pounds of coal to do a certain amount of work, one of the pumps may be at a disadvantage on account of the poor quality of the coal or the inefficiency of the boiler. If each is allowed 1,000 pounds of dry steam, there may be an inequality because of a difference in the steam pressure in the two cases. If, however, each pump is furnished with an equal number of heat units, each has exactly the same stock in trade, and the merit of each pump can be gauged by the use it makes of the heat units furnished it, that is, by the ratio of the work performed to number of heat units supplied.

39. If a pound of water has a temperature of 212°, it requires 966.1 B. T. U. to change it to steam at atmospheric pressure. If the water has originally a lower temperature or is converted into steam at higher pressure, more B. T. U. are required to accomplish the change. Roughly speaking, if the temperature of the feed and pressure of the steam are not given, about 1,000 to 1,100 B. T. U. are equivalent to a pound of steam. Therefore, 1,000 pounds of steam are equivalent to about 1,000 × 1,000 = 1,000,000 B. T. U.

40. Looking at the question in another light, a pound of good coal when burned produces about 13,500 to 14,000 B. T. U. by the combustion. A boiler of fairly good efficiency will utilize perhaps 10,000 of these 13,500 B. T. U., the rest being lost by radiation, in the production of chimney draft, and in other ways. From 100 pounds of coal the boiler is able to extract 100 × 10,000 = 1,000,000 B. T. U., which are eventually given up to the pump. It thus appears that 100 pounds of coal and 1,000 pounds of steam are each approximately equivalent to 1,000,000 B. T. U.; for this reason, the committee of The American Society of Mechanical Engineers recommended that the new basis for estimating duty should be 1,000,000 B. T. U.

41. The heat-unit basis is now very extensively used and is recommended in preference to the others. It may be expressed as follows:

The duty of a pumping engine is equal to the total number of foot pounds of work actually done by the pump divided by the total number of heat units in the steam used by the pump, and this quotient multiplied by 1,000,000. The heat units in the steam used for driving the auxiliary machinery, such as the air pump and circulating pump of the condenser, if one is used, and the boiler feed pumps are charged as heat units supplied to the pump.

42. The number of foot-pounds of work done by the pump is to be found as follows: A pressure ga[illegible] is attached to the discharge pipe and a vacuum gau

suction pipe, both as near the pump as convenient; then the net pressure against which the pump plunger works is equal to the sum or difference in the pressures shown by these two gauges increased by the hydrostatic pressure due to the difference in level of the points in the pipes to which they are attached. In case the gauge in the suction pipe indicates a vacuum, the sum of the pressures indicated by the gauges is taken, but when the water flows into the suction pipe under a head, so that the suction gauge indicates a pressure above the atmospheric pressure, the difference in the two pressures indicated by the gauges is taken.

43. The number of foot-pounds of work done during the trial is equal to the continued product of the net area of the plunger in square inches (making allowance for piston rods), the length of the plunger stroke in feet, the number of plunger strokes made during the trial, and the net pressure in pounds per square inch against which the plungers work.

44. The pressure corresponding to the vacuum in inches indicated by the gauge on the suction pipe is found by multiplying the gauge reading in inches by .4914, and the pressure corresponding to the difference in the level of the two gauges by multiplying this difference in feet by .434. The number of heat units furnished to the pump is the number of British thermal units in the steam from the boilers and is to be determined by an evaporation test of the boilers.

Rule 16.—*To determine the duty of a pump per 1,000,000 B. T. U., multiply the net pressure against which the plunger works, in pounds per square inch, by the net area of the plunger in square inches, by the average length of stroke in feet, the total number of delivery strokes made during the trial, and by 1,000,000. Divide the product by the total number of B. T. U. supplied during the trial.*

Or, $$D = \frac{1{,}000{,}000\,(P \pm p + S)\,A\,L\,N}{H},$$

where $D =$ duty;

$P =$ pressure in pounds per square inch in the discharge pipe;

$p =$ pressure in pounds per square inch in the suction pipe, to be added in case of a vacuum and to be subtracted in case of pressure above atmospheric pressure in the suction pipe;

$S =$ pressure in pounds per square inch corresponding to difference in level between the gauges;

$A =$ average effective area of plunger in square inches;

$L =$ length of stroke of pump plunger in feet;

$N =$ total number of delivery strokes;

$H =$ total number of B. T. U. supplied.

EXAMPLE.—A crank-and-flywheel pump has two double-acting water plungers, each 20 inches in diameter and 36 inches stroke. Each plunger has a piston rod 3 inches in diameter extending through one pump-cylinder head.

During a 10-hour duty trial the total heat in the steam supplied to the engine was 35,752,340 B. T. U. and the engine made 9,527 revolutions. If the average pressure indicated by a gauge on the discharge pipe was 95½ pounds, the average vacuum indicated by a gauge on the suction pipe 8¼ inches, and the difference in level between the centers of the vacuum and the pressure gauge 8 feet, what was the duty?

SOLUTION.—The area of a plunger 20 inches in diameter is 314.16 square inches and the cross-sectional area of a rod 3 inches in diameter is 7.07 square inches. Since the rod extends through only one end of the pump cylinder, the average effective area of the two ends of each plunger is $314.16 - \frac{7.07}{2} = 310.63$ square inches.

The pressure corresponding to a vacuum of 8¼ inches is $p = 8.25 \times .4914 = 4.05$ pounds per square inch, and the pressure corresponding to a difference in level of 8 feet is $S = 8 \times .434 = 3.47$ pounds per square inch.

Since there are two double-acting plungers, the total number of plunger strokes corresponding to 9,527 revolutions is $N = 9{,}527 \times 4 = 38{,}108$.

Applying rule **16**, we get

$$D = \frac{1{,}000{,}000 \times (95.5 + 4.05 + 3.47) \times 310.63 \times 3 \times 38{,}108}{35{,}752{,}340}$$

$= 102{,}328{,}800$ ft.-lb. per 1,000,000 B. T. U. Ans.

DUTY BASED ON VOLUME OR WEIGHT PUMPED.

45. In large pumping plants it often happens that the pressure pumped against is either constant or practically so. In such a plant a record is often kept for the purpose of comparing the performance of the plant from week to week or month to month with its former performances. The records may be kept in number of gallons pumped per pound of coal; in cubic feet pumped per pound of coal; in weight of water in pounds or tons pumped per pound of coal; or the record may be kept per ton or bushel of coal, etc. Duty computed on such a basis is spoken of as **gallon duty, cubic-foot duty, pound duty, ton duty,** etc.; while such a duty is very valuable in showing variations in efficiency of a given plant at different times, it cannot be used as a basis of comparison between the performances of different pumping plants, and when so used will be utterly misleading.

Instead of keeping the records in terms of quantity of water pumped per pound of coal, they may advantageously be kept in terms of water pumped per dollar; the records then show variations in efficiency in their true light.

EXPRESSING THE DUTY OF A PUMP.

46. The question "in what terms shall the duty of a pump be expressed" depends for its answer on the purpose for which it is required that the duty be known. If the duty is merely required to be known in order that the performances of a given pump at different times may be compared with one another, the duty may be based on coal consumption, steam consumption, or volume pumped per some unit of fuel or money. If, however, the performance of a pump is to be compared with that of others working probably under entirely different conditions, the foot-pounds of work done per 1,000,000 B. T. U. is the only true basis of comparison.

AVERAGE DUTIES.

47. Small direct-acting pumps for general service have a duty of 15,000,000 foot-pounds per 1,000 pounds of steam used. Compound direct-acting pumps of 5,000,000 gallons capacity in 24 hours should give a duty of 50,000,000 foot-pounds per 1,000 pounds of steam used. Large municipal pumping engines of 20,000,000 gallons capacity in 24 hours have given a duty of 160,000,000 foot-pounds per 1,000 pounds of dry steam used by the engine.

Centrifugal and rotary pumps have a duty depending on the type of engine used to drive them, and since they usually run at high speed and the conditions for economical performance are good, an economical type of engine can be used and the duty of the combined unit thus made to compare very favorably with that of the reciprocating pump.

48. Tests of the duty of pumps and pumping engines have generally been made when the machinery was in first-class condition. It is customary to run these machines from 6 months to 1 year after they are installed before making the test, the object being to bring all the journals into a good bearing condition; also, the piston and all the other rubbing surfaces will be much improved by the polishing and the working of oil into the pores of the iron during running. These high duties can only be maintained by the closest attention to every detail by the operating engineer. Indicator cards should be taken from both the steam and the water ends of the pumps every week and closely compared with previous indications to see that the highest state of efficiency is being maintained within the working parts of the pump.

EFFICIENCY OF VARIOUS TYPES OF PUMPS.

49. When the **efficiency of a pump** is spoken of, its *mechanical* efficiency is generally meant, unless stated otherwise. This is measured by dividing the actual or net horse-wer of the machine by its indicated horsepower, and the otient, when multiplied by 100, will be the efficiency

expressed in per cent. Very small direct-acting steam pumps have an efficiency of about 50 per cent., the efficiency increasing with the size of the pump up to about 80 per cent. The efficiency of direct-acting steam pumps and also of pumps in general increases with the size by reason of the decrease in the ratio that the frictional resistances bear to the indicated horsepower as the size of the pipes and passages is increased. The reason that the frictional resistances decrease can readily be seen when it is considered that by doubling the diameter of a pipe and keeping the velocity of flow the same, the discharge will be increased four times, while the surface that the water is rubbing against is only doubled.

50. Large vertical municipal pumping engines have shown an efficiency as high as 96 per cent.; horizontal medium-size crank-and-flywheel pumps show efficiencies as high as 90 per cent. The efficiency of centrifugal, rotary, and screw pumps varies between 40 and 66 per cent., about, depending on the size; small pumps are less efficient than larger ones. This efficiency of centrifugal, rotary, and screw pumps is the *efficiency of the pump itself*, and not the combined efficiency of the pump and engine, or motor, driving it.

SIZE OF SUCTION AND DELIVERY PIPES.

51. Experience has demonstrated that for satisfactory work the flow of water in the suction pipes of pumps should not exceed 200 feet per minute, and it should not be more than 500 feet in the delivery pipe for a duplex double-acting pump, or 400 feet for a single-cylinder double-acting pump.

Knowing the volume of water that is to flow through or to be discharged from a pipe in 1 minute, the area of the suction and delivery pipes can readily be determined.

The volume of water in cubic feet discharged from a pipe in 1 minute is equal to the velocity in feet per minute times the area of the pipe in square feet. Then,

$$\text{the area of the pipe} = \frac{\text{volume in cubic feet per minute}}{\text{velocity in feet per minute}}.$$

As there are 144 square inches in a square foot,

$$\text{the area of the pipe in square inches} = \frac{144 \times \text{volume in cubic feet per minute}}{\text{velocity in feet per minute}}.$$

Rule 17.—*To find the area of a pipe in square inches to discharge a given volume of water per minute, divide the product of the volume in cubic feet and 144 by the allowable velocity in feet per minute.*

Or,
$$A = \frac{144\,V}{v},$$

where A = area of pipe in square inches;
V = volume to be discharged per minute;
v = allowable velocity.

When the weight of water is given in pounds, divide it by 62.5 to reduce it to cubic feet; when the volume is given in Winchester gallons, divide it by 7.48 to reduce it to cubic feet.

EXAMPLE.—What should be the areas of the suction and delivery pipes for a single double-acting pump that is to discharge 6,250 pounds of water per minute?

SOLUTION.—Reducing the weight to cubic feet, we have $\frac{6{,}250}{62.5}$ = 100 cubic feet. Then, applying rule **17**, we have

$$A = \frac{144 \times 100}{200} = 72 \text{ square inches}$$

as the area of the suction pipe, and

$$A = \frac{144 \times 100}{400} = 36 \text{ square inches}$$

as the area of the delivery pipe. The nearest standard nominal sizes of pipe to be used would be 10-inch and 7-inch. Ans.

52. The velocity with which water will flow through the delivery pipe of a pump when the area of the water cylinder, the area of the delivery pipe, and the piston speed of the pump are known, is given by the following rule:

Rule 18.—*Multiply the area of the water piston by the piston speed and divide this product by the area of the delivery pipe.*

Or, $$v = \frac{a\,S}{A},$$

where v = velocity in feet per minute;
A = area of delivery pipe in square inches;
a = area of water piston in square inches;
S = piston speed in feet per minute.

EXAMPLE.—If the water piston of a pump has an area of 12 square inches and moves at a speed of 100 feet per minute, what will be the velocity of the water in the delivery pipe if the latter has an area of 2 square inches?

SOLUTION.—Applying rule **18**, we get

$$v = \frac{12 \times 100}{2} = 600 \text{ ft. per min. Ans.}$$

EXAMPLES FOR PRACTICE.

1. The plungers of a center-packed double-acting duplex pump are 20 inches in diameter and the plunger rods are $3\frac{1}{2}$ inches in diameter. Each plunger makes 45 strokes per minute, the length of stroke being 24 inches. What is the displacement in cubic feet per minute?
Ans. 386.69 cu. ft.

2. In the above example, if the pump delivers but 360 cubic feet per minute, what is the slip? Ans. 6.9 per cent.

3. Approximately, what horsepower will be required to deliver 60 cubic feet of water per minute, the total lift being 470 feet?
Ans. 76.3 H. P.

4. What is the probable horsepower required to deliver 3,500 gallons of water per hour against a pressure of 115 pounds per square inch?
Ans. 5.57 H. P.

5. A pump driven by a 25-horsepower engine is to discharge 60 cubic feet of water per minute. How high may this water be lifted, approximately? Ans. 154 ft.

6. Approximately, how many gallons of water per hour can a pump driven by a 30-horsepower engine deliver at a height of 65 feet?
Ans. 1,278.3 gallons.

7. Approximately, against what pressure can a 20-horsepower pump discharge 2,500 cubic feet of water per hour?
Ans. 77 lb. per sq. in.

8. About how [illegible] a [illegible]-horse-power pump [illegible] discharge against a pressure of 1[illegible] pounds per square inch? Ans. [illegible] per min.

9. A pump [illegible] discharge [illegible] per hour. If the speed of the plunger is [illegible] feet per minute, what [illegible] the diameter of the plunger? Ans. [illegible] in., nearly.

10. If the plunger of a double-acting pump [illegible] inches in diameter and the length of stroke is 24 inches, how many gallons of water per hour may the pump be expected to deliver [illegible] making 4[illegible] strokes per minute? Ans. [illegible] gal. per hr.

11. Roughly estimate the discharge in gallons of a direct-acting steam pump having a plunger 7 inches in diameter.

Ans. [illegible] gal. per min.

12. If the piston speed is 90 feet per minute and the length of stroke 2 feet, how many strokes per minute will the pump make? Ans. 45.

13. Calculate the minimum diameter of the steam piston for a pump having a plunger 12 inches in diameter, the pressure to be pumped against being 175 pounds per square inch and the available steam pressure 100 pounds per square inch. Ans. 1[illegible] in.

14. What is the duty per 100 pounds of coal of a pump that raises [illegible] pounds of water 125 feet and requires 110 pounds of coal to perform the operation? Ans. [illegible] ft.-lb.

15. If 20,000 pounds of steam are consumed by a pump in lifting 1,200,000 gallons of water 150 feet, what is the duty per 1,000 pounds of dry steam? Ans. 75,000,000 ft.-lb.

16. A double-acting pump has a stroke of 40 inches, the diameter of the plunger is [illegible] inches and the diameter of the piston rod, which extends through the pump-cylinder head, is 3[illegible] inches. During a 12-hour duty trial the total heat supplied to the engine was 47,652,500 B. T. U. and the pump made 21,[illegible] strokes. What was the duty of the pump per 1,000,000 B. T. U. if the average pressure indicated by the gauge on the discharge pipe was [illegible] pounds, the average vacuum indicated by a gauge on the suction pipe [illegible] inches, and the difference in level between the centers of the vacuum gauge and pressure gauge was 10 feet?

Ans. 93,[illegible] ft.-lb.

17. [illegible] the suction and delivery pipes for a single-[illegible] 1,250 gallons of water per minute.

Ans. { Suction pipe, 120.3 sq. in.
Delivery pipe, 60.15 sq. in.

18. [illegible] pump has a speed of 85 feet [illegible] be the velocity of the [illegible] of 6 square inches?

Ans. 400.5 ft. per min.

SELECTION OF PUMPS.

SERVICE OF DIFFERENT TYPES OF PUMPS.

53. Introduction.—The service for which a pump is required determines its general type, that is, whether it is to be a plunger pump, a rotary pump, a centrifugal pump, or a screw pump.

54. Reciprocating Pumps.—The various types of reciprocating pumps are selected when high efficiency is required and a fluid for which they are suited is to be pumped.

55. Rotary Pumps.—The rotary pump is chosen when the fluid to be pumped is water holding in suspension large masses of soft material. It is much used in paper mills for pumping the pulp from one stage of its manufacture to another. Rotary pumps are small and occupy, relatively, but little space for their capacity; they are also light, simple, and inexpensive, but are low in efficiency and are short lived, particularly if the material pumped contains much sand or other grit. The rotary pump is used with good success on some steam fire-engines, where light weight and simplicity are more important than high efficiency.

56. Centrifugal Pumps.—Centrifugal pumps are used where large volumes of water are to be lifted to moderate heights. They are also well adapted for pumping large quantities of dirty water, and, hence, are also much used for dredging and for sewage pumping. The efficiency of the centrifugal pump is low, but it is extremely simple and occupies comparatively little space for its capacity. Like the rotary pump, it has no valves and the flow is continuous. It is less affected by sand and grit than is the rotary pump. Neither the rotary pump nor the centrifugal pump requires much, if any, foundation.

57. Displacement Pumps.—Under the head of displacement pumps may be classed the pulsometer, which has

no running parts. This type of pump is well adapted for pumping all kinds of gritty water and is used for sinking and contractor's purposes. It is very simple in construction, low in first cost, and is not liable to get out of order. The class of pumps known as air lifts are principally used for artesian-well service; they require an air compressor for operation, but the apparatus itself is simple and low in first cost.

58. Screw Pumps.—Screw pumps are adapted for the handling of thick liquids, such as hot tar, pitch, paraffin, soap, etc. They have a uniform discharge and occupy small space; a much higher efficiency is claimed for them than for rotary or centrifugal pumps.

RECIPROCATING PUMPS.

CLASSIFICATION.

59. The reciprocating pump is, in general, the most efficient and hence the most common pump. It is built in a large variety of designs to suit different conditions and varies in size between very wide limits. Reciprocating pumps may be classified in accordance with the service for which they are intended as boiler-feed pumps, general-service pumps, tank or light-service pumps, fire pumps, low steam-pressure pumps, pressure pumps, mine pumps, sinking pumps, ballast pumps, wrecking pumps, deep-well pumps, sewage pumps, vacuum pumps, power pumps, municipal pumping engines, etc.

BOILER-FEED PUMPS.

60. Boiler-feed pumps are used for supplying steam boilers with their necessary water supply. For low pressures they are usually made of the piston pattern or the inside packed plunger patterns. The cylinders are generally brass lined; the valves are brass or hard composition, with

composition springs and guards, and the pumps, hence, are suitable for handling hot water. For pressures above 135 pounds the outside-packed plunger type is preferred. Boiler-feed pumps are made both vertical and horizontal and for pressures from 50 pounds to 300 pounds per square inch. They vary in size from those having water plungers 1 inch in diameter to those having plungers 10 inches in diameter. The single-cylinder type is much used for boiler feeding, but, perhaps undeservedly, they have not the reputation for continuous action under all circumstances that is given to the duplex pump. Power pumps are often used for boiler feeding.

61. Whenever possible the boiler feeding apparatus should be in duplicate, so that the stoppage of one set will not affect the running of the plant. This end is generally secured by installing both a pump and an injector, each having a capacity sufficient for the needs of the plant.

62. Steam-driven crank-and-flywheel pumps are occasionally used, but they are open to the serious objection that they cannot always be run slow enough to suit the demand without stopping on the centers. In very large electrical installations, the electrically driven power pump is the most economical and satisfactory arrangement. Mills and factories often use the two-throw power pump having a movable crankpin, by means of which the stroke and hence the quantity of water pumped can be adjusted to suit the requirements. By this means a constant supply of feedwater equal to the demands for steam can be obtained, which is superior to the practice of pumping large quantities of water into the boilers at intervals. Boiler-feed pumps should not be required to run faster than 100 feet per minute piston speed. The velocity of water through the suction pipe should not exceed 200 feet and through the delivery should not be more than 400 feet. If the pipes are long or fitted with elbows, the velocity should be correspondingly decreased.

63. In determining the proper capacity of a pump for boiler feeding, the pump should be selected in reference to the amount of steam the boilers must supply. This is rarely only the amount used by the engine; in fact, in many industrial establishments much more steam is needed for other machinery than for the engine. Hence, it is best to always base the estimate as to the amount of water required on the maximum capacity of the boilers.

64. The maximum water consumption may be estimated in pounds per minute by one of the following rules, which hold good for average practice under natural draft. It will be observed that no rule based on the so-called "boiler horsepower" is given, for the reason that this is too variable a quantity to place any reliance on.

Rule 19.—*For plain cylindrical boilers multiply the product of the length and diameter in feet by .18.*

Rule 20.—*For tubular boilers multiply the heating surface in square feet by .06.*

Rule 21.—*Multiply the grate surface in square feet by 1.7.*

Rule 22.—*Multiply the estimated coal consumption in pounds per hour by .17.*

65. Whenever possible the feed-pumps should be located in the boiler room, so as to be directly in sight and in charge of the boiler attendant. In very large installations it is common to arrange the pumps in a separate pump house, they being then in charge of one of the assistant engineers, the boiler attendants regulating the supply to each battery by valves in the feedpipes.

GENERAL-SERVICE PUMPS.

66. **General-service pumps** are a line of pumps placed on the market by many of the pump builders to be used for any service where the water pressure does not exceed 150 pounds. They are generally of the plunger type and are built in sizes varying from those having a 4-inch to those

having a 16-inch plunger, and of a capacity varying from 100 gallons to 2,500 gallons per minute. They may be used for any service such as boiler feeding, fire, hydraulic elevator, or anywhere where the pressure to be pumped against is not greater than the limit stated.

TANK OR LIGHT-SERVICE PUMPS.

67. Tank or light-service pumps are of the same general form and interior construction as general-service pumps, except that the plungers are much larger in proportion to the steam cylinders, equalling or exceeding them in diameter. Such pumps cannot be used to feed their own boilers, but they are sometimes fitted with an attached pump for this purpose. Light-service pumps are commonly built of the same capacity as general-service pumps, but can only pump against low pressures.

FIRE PUMPS.

68. Fire pumps are most frequently of the duplex double-acting type with a ratio of area of steam cylinder to water piston of about 4 to 1. The duplex engine is chosen for this service on account of its simplicity and the peculiar adaptability of its motion to the high speed that is sometimes required in this service. A fire pump is frequently fitted up with a number of nozzles for hose connection. It should have relief valves, air and vacuum chambers of large capacity, steam and water gauges, priming pipes, and all the necessary valves.

Fire pumps, as implied by the name, are intended for use in case of fire, and are required to throw a large volume of water at high pressure.

LOW-PRESSURE STEAM PUMPS.

69. Low-pressure steam pumps are pumps intended for localities where only a low steam pressure is available, as in apartment houses, public and private buildings, etc.,

in which the pressure at which the steam heating system is worked does not exceed 5 to 10 pounds per square inch. The ratio of cylinder areas is about 9 to 1, the steam cylinder being the larger. Otherwise they are fitted up similar to pumps for general service. In some cases a hand power attachment is provided so that the pump can be worked by hand when the steam pressure is down.

PRESSURE PUMPS.

70. Pressure pumps are designed especially for use in connection with hydraulic lifts, cranes, cotton presses, testing machines, hydraulic machine tools of all kinds, and hydraulic presses, also for oil pipe lines, mining purposes, and such services as require the delivery of liquids under very heavy pressure. These pumps are invariably of the outside-packed plunger type and generally have four single-acting plungers working in the ends of the water cylinders, the latter having a central partition. The water valves are contained in small chambers capable of resisting very heavy pressures and ingeniously arranged for ready access. All materials used in the construction of the water end must be first class and suitable to the pressure used, which ranges from 750 pounds per square inch to 1,500 pounds per square inch. The water ends of these pumps are frequently made of hard, close-grained composition for medium pressures, and of steel castings for the heavier pressures.

MINE PUMPS.

71. Perhaps no other class of pump requires as much experience and skill to select as the mine pump. The reason for this is the wide variations in service, conditions of operation, head or pressure to be worked against, and the destructive nature of the water to be pumped. Nearly all the pumps at present installed are placed entirely below the surface. In former times the Cornish, or bull, pump was the favorite, but it is today abandoned for the more compact

and less expensive modern mine pump. The water end of the modern high-pressure mine pump may be described as having outside-packed plungers; strong circular valve pots independent of one another, but bolted to the working chamber, to the suction and delivery pipes, and to one another. Frequently the whole inside of the water end of the pump, from the suction nozzle to the discharge flange, is lined with wood, lead, or some other acid-resisting substance. Sometimes the entire water end is made of an acid-resisting bronze. Unless the service is light the outside-packed plunger pump is recommended for mine work; the valves should be preferably metallic valves in separate pots or chambers. Whether the pump shall be simple, compound, or triple expansion depends much on the price of fuel. In the anthracite coal regions the compound mine pump is now very common for sizes as small as 1,000,000 gallons in 24 hours, and they are invariably compounded for larger sizes, while the triple-expansion direct-acting pump is found in several of the mines.

72. Compound crank-and-flywheel high-duty pumps using the steam expansively have but recently been installed in the coal mines; in the iron and copper mines, where the cost of fuel is very high, the highest types of pumping engines have long been used.

73. When the larger types of high-duty pumps are used, the mine workings are generally so arranged that all the water runs to one large basin or sump near which a chamber of sufficient size is cut to contain the pump, which is surrounded and protected by suitable devices to maintain it in a high state of efficiency.

74. In many mines, strength and simplicity are the controlling elements in selection, for the reasons that many mines are compelled to use a large number of medium sized pumps and, for commercial reasons, use only one man whose business it is to make the rounds of the various pumps, giving each one but a few minutes' attention in a day. They generally have to stand rough usage, and the water pumped

is of such a corrosive quality that repeated renewals of parts of the water end are absolutely necessary. After heavy rains or other causes of flooding, the pumps are often required to run for days completely submerged and must pump both themselves and the mine dry. It can be readily seen that a pump for such service must be strong, simple, ready of access, and all of its parts of such construction that they can be readily taken apart or renewed.

SINKING PUMPS.

75. Sinking pumps are used in sinking or deepening mine shafts. There is little choice in their selection; generally speaking, they should be simple, strong, and capable of working in any position. The valves should be of the simplest possible construction and accessible for renewal with a minimum of labor and time. The valve motion should be simple and protected from dirt and drippings. They are regularly built single cylinder and duplex and are steam or electrically driven. With electric sinking pumps the protection of the electrical parts must be very complete.

BALLAST AND WRECKING PUMPS.

76. Ballast and **wrecking pumps** are principally confined to the marine service. The ballast pump is used on steamers having an extensive system of water ballast; also, for handling petroleum in bulk on oil-tank steamers. It is distinctively a special pump. The wrecking pump has a somewhat wider sphere. As its name implies, it is used principally by wrecking companies on the Atlantic and Pacific coasts and along the Lakes and is constructed with particular reference to reliability, portability, and general efficiency. It is well adapted to other services requiring the delivery of large volumes of water within the range of lift by suction. It has no forcing power, the water being merely delivered over the top of the pump, and it is single-acting, the water piston being fitted with valves. It is a

very light form of pump in proportion to the work it will do, is simple, durable, and not liable to derangement or breakage. It is also well adapted to drainage and irrigating purposes.

DEEP-WELL PUMPS.

77. Deep-well pumps, like sinking pumps, give little field for choice except in the pump-driving mechanism, which is as varied as the agent available to operate them, the principal agents being steam, electricity, gas, and windmills. The pump is usually a lifting pump having a bucket packed with numerous hydraulic leathers and working within the casing; it is usually given a very long stroke. These pumps do not handle gritty water successfully. Probably the best practical solution of the deep-well pump problem will be found in the air lift, which in principle and operation is quite simple.

SEWAGE PUMPS.

78. Sewage pumps are built in various types. When the lift is low, which condition is most common in sewage disposal, the centrifugal pump is the cheapest to install, but when economy and efficiency are important factors, the centrifugal pump must give place to the more expensive but more efficient reciprocating pump. Probably the largest single pumping engine ever constructed is the sewage pump for the city of Boston, which has a capacity of 70,000,000 gallons in 24 hours.

79. It will readily be seen that the selection of a type of sewage engine will depend much on the capacity of the installation and the price of fuel delivered at the station. The principal characteristics of the sewage engine are in the valves, which must be provided with very large ports to allow fairly large objects to pass through the pump without obstructing its valves. The valves are frequently made in the form of large leather-faced doors or flap valves, giving

nearly the full area of the pipe. The sewage pump does not differ in other respects from pumps for general service.

POWER PUMPS.

80. Power pumps are among the oldest styles of pumps, and may be developed by driving any type of reciprocating pump by other means than the use of a directly attached steam, gas, or air cylinder. Power pumps are very often geared or belted and with the increasing application of electricity the electric power pump is coming into more extensive use.

81. Power pumps may be used for any service and are frequently found in municipal water works, being often driven by a turbine or a Pelton waterwheel. In large electric-lighting, heat, and power plants, the power pump is much used for boiler feeding; in this case the pumps are usually triplex, giving a steady flow of water, and are driven by electric motors, the current being furnished by the main generators. This is probably the most efficient and economical boiler feeder that has been developed.

82. The power pump is used quite extensively in the mines. An electric motor being the driver, the system admits of many various sized pumps being placed at the different sumps throughout the mines and driven by one large and economical generating unit at the surface.

83. The selection of a power pump in preference to other types depends on conditions that, to some extent, may be gathered from the above applications; the choice, however, depends much on the kind of power available to run the machine. Where water-power is available, either for gearing directly to the pump or for generating electric current to drive the pump at a remote distance, the power pump may advantageously be chosen. It should be remembered in this connection that a steam pump should be installed to take

care of the feedwater when the main engines are stopped and no current is available for driving the power pump.

84. In private houses, hotels, office and public buildings the electric-power pump is a favorite, and to avoid the noise of gears the reduction in speed is made by friction drives of various types; rawhide gearing is also used to some extent. The construction of the water end of power pumps does not differ from other pump constructions for the same service.

MUNICIPAL PUMPING ENGINES.

85. While the **municipal pumping engine** may be of any size and capacity, and while some of the pumps already discussed, as the general-service and power pump, may be, and are, frequently used, the term usually implies the highest type of pumping engine that can be constructed as regards economy and efficiency. The refinement is more exacting as the capacity of the pump increases. For small municipal pumping engines, say of 2,000,000 to 5,000,000 gallons capacity in 24 hours, the compound and triple-expansion direct-acting engine is used, the degree of expansion depending on the price of fuel and the capital available for the investment. For installations of from 5,000,000 to 20,000,000 gallons capacity, the high-duty direct-acting engine, that is, the direct-acting engine with high-duty attachment, and the crank-and-flywheel engine are rivals for the installation; while for large municipal pumping engines above 20,000,000 gallons capacity in 24 hours, the vertical triple-expansion condensing three-crank single-acting, or differential, plunger beam type may be said to have no equal. With the latter type of engine a duty of 160,000,000 foot-pounds of work per 1,000 pounds of steam used by the engine is now common. Steam pressures of 175 pounds are common, while the number of expansions are as high as 22 to 26, and every reasonable device known in the art of steam engineering is used to the end of breaking records in securing a high duty.

VACUUM PUMPS.

86. Vacuum pumps are chiefly used in connection with jet condensers and siphon condensers. A vacuum pump is in reality an air pump, it being used for pumping air out of closed vessels. There are two general types of vacuum pumps, which are **dry vacuum pumps**, or pumps that handle air only, and **wet vacuum pumps**, or pumps that handle both air and water. Vacuum pumps are also used in some manufacturing operations where a high degree of vacuum is required, being used in connection with the vacuum pans found in sugar houses, with glycerin pans, etc.

RELATIVE MERITS OF DIRECT-ACTING AND CRANK-AND-FLYWHEEL PUMPS.

87. The relative merits of the two types of machine for a particular size, other conditions being equal, are such that it is a very difficult matter to decide which type is superior. For pumping small quantities of water, say up to 700 gallons per minute, and in localities where coal is not expensive, the direct-acting pump, either simple or compound, should prove a good investment. The objection to the direct-acting pump for large sizes is its waste of steam as compared with the crank-and-flywheel pump; it has an additional objection that is sometimes argued against it, which is *short-stroking*. This defect reduces its economical performance in that it requires some steam to fill up the space due to the incomplete stroke, but since the incomplete stroke is due to too high a compression, the compressed steam must have nearly filled the space before fresh steam was admitted, so that the loss is not so very great after all. Short-stroking reduces the capacity of the machine somewhat. In the common types of direct-acting pumps, the steam is not worked expansively; in compound and triple-expansion pumps, some degree of expansion is obtained, usually a little more than the ratio of high-pressure cylinder to low-pressure cylinder. By making the reciprocating parts

heavy and running the pump at some fixed minimum speed, an early cut-off can be effected in the high-pressure cylinder, the balance of the stroke being completed by the inertia of the reciprocating parts; in this way an increased degree of expansion is possible.

Another method of securing a considerable degree of expansion in the direct-acting pump is by means of the high-duty attachment. With the same degree of safety the speed of the direct-acting pump is very much less than is possible with the crank-and-flywheel pump. The direct-acting pump in which any attempt is made at economy will occupy quite as much space as the crank-and-flywheel pump of the same capacity, but the direct-acting pump is lower in first cost

88. Probably the most objectionable feature of the crank-and-flywheel pump, which is an inherent one, is that the velocity of discharge varies throughout the stroke. This is due to the fact that while the flywheel rotates at a uniform speed, the pistons and plungers move with a variable speed, varying from zero at the beginning of the stroke to the maximum speed near mid-stroke and then decreasing to zero at the end of the stroke. This variation in velocity produces shocks, and hence requires the water end of a flywheel pump to be of heavier construction than a similar end for a direct-acting pump. The valve area of a flywheel pump requires to be considerably larger than for a direct-acting pump, not only because of its capacity for higher speeds, but also because the velocity of the plunger, when the connecting-rod is at right angles to the crank arm, is somewhat in excess of 1.57 times the mean velocity of the plunger. In addition to the greater valve area and strength required in flywheel pumps, it is necessary to use some means to reduce the shocks to the mechanism and parts of the pump. This is accomplished by providing large air chambers, preferably one over each deck for high pressures; for very high pressures and long columns of water, an alleviator is necessary.

89. The main advantage of the crank-and-flywheel pump is its economy, which, in turn, is due to the fact that the

steam may be expanded to any permissible degree; it also readily admits of all the refinements known of securing high-duty performance, and with a proper arrangement of details, it can be made quite as safe as ordinary machines. For extreme high duties the crank-and-flywheel pump is always chosen, and to reduce the shocks due to a variable discharge a favorite type is the three-crank machine. The combined delivery from three plungers is tolerably uniform and the arrangement readily lends itself to the extremely economical triple-expansion condensing engine.

90. The crank-and-flywheel engine is more expensive than the direct-acting machine, and when high degrees of expansion are used occupies considerably more room. It is generally more complicated, but is more accessible, except in such cases as where an effort is made to minimize space, when by making the engine back-acting it is liable to become quite inaccessible.

91. The piston speed of direct-acting pumps rarely exceeds 100 feet per minute, while the piston speed of crank-and-flywheel pumps is commonly 300 feet and sometimes 400 feet. With pumps of the controlled-valve type, piston speeds of 560 feet are reached. This difference in the piston speed of the direct-acting and crank-and-flywheel pumps shows that they must be compared on the basis of water delivered rather than on the relative size of similar parts.

92. Even for very small sizes, the crank pump is sure in its action and is not liable to get out of order; this cannot be claimed for some of the single-cylinder direct-acting pumps having steam-thrown valves. The crank pump is limited as to its slowest speed, however, since the speed must be sufficient to store energy enough in the flywheel to carry the crank over the dead centers. This objection can be overcome to a great extent by using the by-pass, which allows part of the water to be returned to the suction, thus decreasing the work on the pump.

ELEVATORS.

(PART 1.)

GENERAL DESCRIPTION OF ELEVATORS.

INTRODUCTION.

1. Definition.—The term **elevator** is applied to that class of hoisting machinery in which a cage, cab, car, or platform is raised and lowered between fixed stops or landings.

2. Principal Parts.—In all complete elevators the following principal parts are easily distinguished:

1. The motor.
2. The car (cage, cab, or platform) and its principal guides.
3. The devices transmitting power from the motor to the car.
4. The counterbalance weights and their guides.
5. The controlling devices.
6. The safety devices.
7. Accessories.

MOTORS AND CLASSIFICATION.

3. Various kinds of motive power and, consequently, motors are used to run elevators. In practice, the classification of elevators is made according to the motive power used. The most generally accepted one, which is also the

one that we shall adopt, is as follows: *Hand-power elevators*, *belt elevators*, *steam elevators*, *electric elevators*, and *hydraulic elevators*.

CARS AND GUIDES.

4. It is evident that elevator cars must be different for various purposes. All of them, however, have a **platform** upon which the load rests, and with few exceptions, as in sidewalk elevators, two upright **posts** connected by a **crosshead** to which the ropes are attached. Each upright carries two **guide shoes,** one on top and one on the bottom, which fit over the **guides.** The latter consist either of hardwood strips of square cross-section or bars of **T** iron carried up inside the hoistway and attached to suitable supports. According to the location of the elevator shaft in the building and the accessibility of the guides, they are placed either in the center of two opposite sides of the shaft or in two diametrically oppósite corners, necessitating the upright posts of the cars to be placed in like manner with reference to the platforms. In the first case they are called **side-post elevators**; in the other case, **corner-post elevators.** The guide shoes are usually of cast iron, and in the case of iron guides are lined with Babbitt metal.

For freight service the cars are of the simplest kind; they are generally made of wood with iron fixtures and bracings. For passenger service a complete cage is built upon the platform, preventing any possible contact of the passenger with the hoistway. Passenger cars are now mostly built wholly of metal, though many wooden ones are in operation. Various styles of cars are shown in subsequent illustrations.

TRANSMITTING DEVICES.

5. Various transmitting devices are used with different kinds of motive power. Hydraulic elevators and a certain electric elevator have peculiar transmitting devices of their

own, which will be described in connection with these elevators. All belt and steam elevators and the majority of hand and electric elevators are of the **drum type,** that is, of a type in which the transmitting devices include a drum and rope. All these elevators, therefore, have certain peculiarities in common, which are pointed out beforehand to avoid repetition.

6. Side Travel of Ropes in Drum Elevators.—An inherent feature of the rope-and-drum drive is the deflection of the rope as it winds upon the drum. Let *D*, Fig. 1, be the winding drum and *S* the nearest sheave from which the

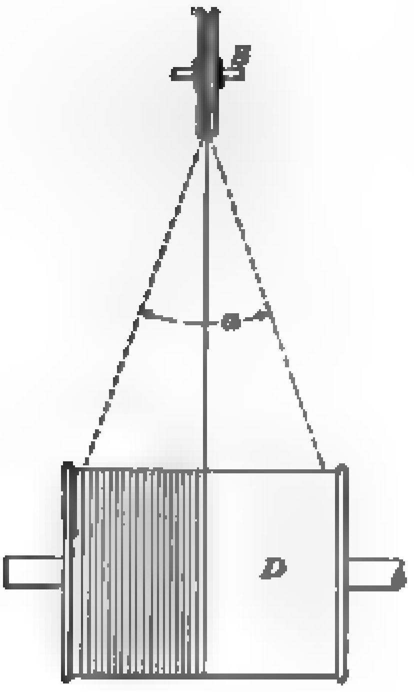


FIG. 1.

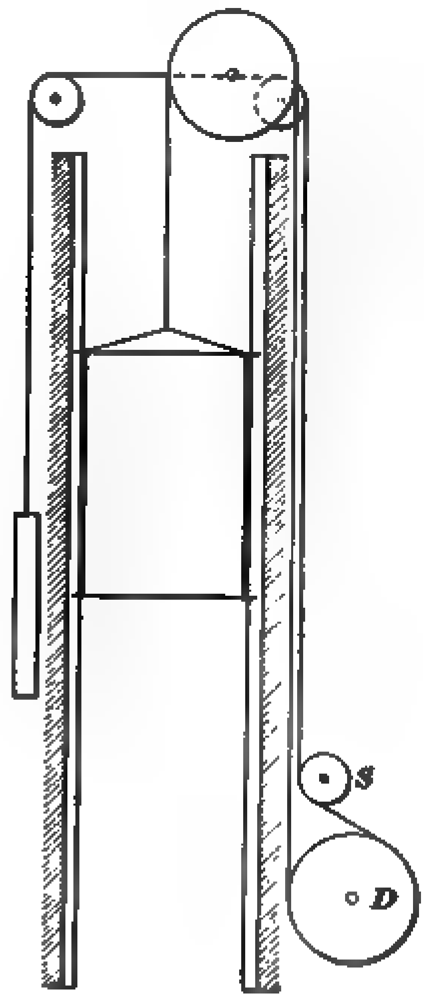


FIG. 2.

rope passes on to the car. It is plain that only at a certain position of the car the rope runs over the sheave exactly straight; in all other positions it must be guided into the sheave. If the distance between the drum and the nearest

sheave is great, as, for instance, when the rope passes straight up from a drum located at the foot of the hoistway to an overhead sheave, the deflection measured by the angle a, Fig. 1, is but small and readily taken care of by the depth of the grooves in either sheave or drum. But if the distance is small, danger exists that the rope will jump the grooves of the drum and "ride" on itself, which may evidently cause accident. Such small distances between the drum and the nearest sheave are frequently unavoidable. Thus, in the case shown by Fig. 2, where it is required that the ropes of both the car and the counterweight shall run within the hoistway, the hoisting rope must be led over an **idler** S very near the drum D, and the counterweight rope, in the case shown, will surely "ride" if no provision be made against it. These idlers are, therefore, so mounted on their shafts that they can follow the ropes as they wind upon and unwind from the drums. Such a traveling idler is sometimes spoken of as a **vibrator**. In most cases it is found sufficient to mount the idler loosely on a smooth shaft and to rely on the pressure of the rope against the sides of the groove in the idler to shift the latter along. That careful lubrication is essential to the proper working of this arrangement is evident.

7. The constant chafing of the rope against the sides of the idler groove, which is unavoidable in the arrangement : mentioned, is an objection, and if considered of suffi- it influence on the life of the rope, is avoided by giving : idler a positive motion in the direction of its shaft. gs. 3 and 4 show two ways of accomplishing this.

'n Fig. 3, the idler shaft a is connected to the drum shaft a chain and sprocket wheels, the hub of the sprocket eel b on the idler shaft being a nut fitting over a square read cut on the shaft and being held from moving side- se. This causes the shaft to move in the direction of its s, a feather preventing it from rotating. The idler c ns loosely on the shaft, but moves back and forth with it, to collars on the shaft.

8. In the arrangement shown in Fig. 4, the chain connection is dispensed with. The idler shaft *a* is threaded but is held stationary, and the idler hub is a nut, so that while the idler revolves by the friction of the rope it travels back and forth. Since there is no positive connection between the drum shaft and the idler shaft, any slippage of the rope on the idler will bring the arrangement out of adjustment. For this reason the following plan for automatic readjustment was adopted by the Otis Elevator Company.

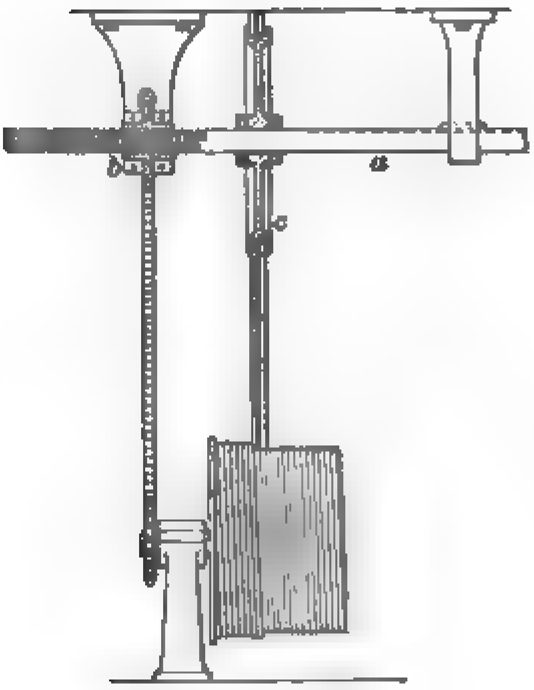


FIG. 3.

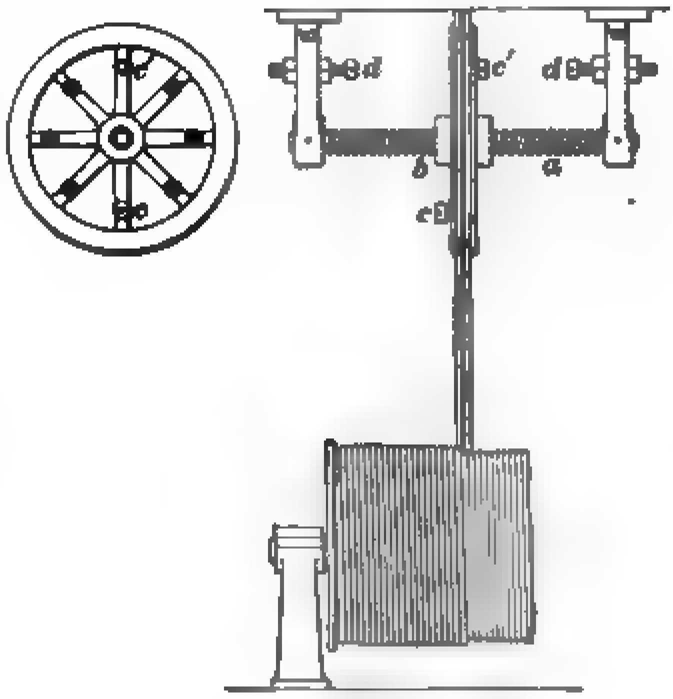


FIG. 4.

The idler is provided with stop screws *c* and *c'* that engage at the end of the travel with fixed stops *d*, *d* on the shaft supports. If for any reason slippage has occurred and the idler lags behind, it will be ahead of the rope on the following return trip and engage the stop on the shaft support before the drum comes to rest; the idler being thus prevented from turning, the rope will slip until the drum stops; on the following trip the idler will leave the stop at once and, thus readjusted, will follow the rope correctly. To allow of a fine initial adjustment, the idler has eight spokes, each drilled and tapped to receive the screw stops *c*, *c'*.

9. Absorption of Vibration Due to Gearing.—An inherent feature of all drum elevators is a certain amount of unpleasant vibration transmitted from the gearing through the drum and hoisting rope to the car. This vibration is especially noticeable in spur-geared machines; but it also exists in worm geared ones, owing to the fact that a certain amount of backlash, be it ever so little, always exists. To reduce these vibrations to a minimum, elastic buffers, generally of rubber, are sometimes interposed between the drum and the next adjacent gear. Fig. 5 shows a way in

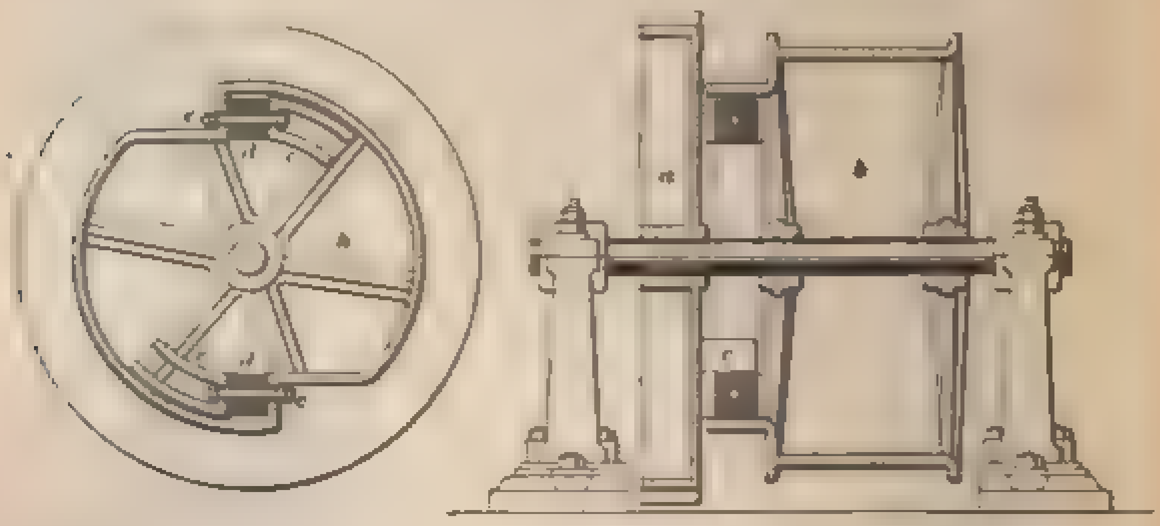


FIG. 5.

which this may be done. The gear-wheel *a* is keyed to the shaft, while the drum *b* is loose. The gear-wheel drives the drum by means of drivers *c*, *c*, which are cast in one with the gear wheel. These drivers, instead of butting directly against metallic surfaces of the drum, butt against rubber blocks, or buffers, *d*, *d*. These buffers must be given a certain amount of initial tension, which is accomplished by the tie-bolts *e*, *e* that tie the drum and the gear-wheel together. The end view shown in Fig. 5 is taken between the gear-wheel *a* and the drum *b*, which accounts for the fact that while the drivers *c*, *c* are seen, the gear-wheel is absent. The tie-bolts must have jam nuts or some other efficient nut-locking device, which should be examined occasionally to see if the bolts have become slack.

COUNTERBALANCING.

10. In any elevator, the weight of the car and its fixtures is constant, and hence is easily **counterbalanced** to any extent desired. The simplest way to do this is to attach another rope, besides the hoisting rope, to the car, leading this second rope over one or more overhead sheaves and suspending from it the counterbalance weight, or the **counterweight,** as it is generally called, as shown in the diagrammatic illustration given in Fig. 6. In order that the car may descend when empty, the counterweight must, when so attached, always be less than the weight of the empty car with its fixtures. Evidently, with such an arrangement, no power is needed for the down trip of the car, while on the up trip, the motor must develop enough power to raise the maximum load, plus the unbalanced weight of the car. In all types of elevators in which the motor furnishes power only on the upward trip of the car, as in hydraulic elevators, for instance, the arrangement shown in Fig. 6 is the only method of counterbalancing available.

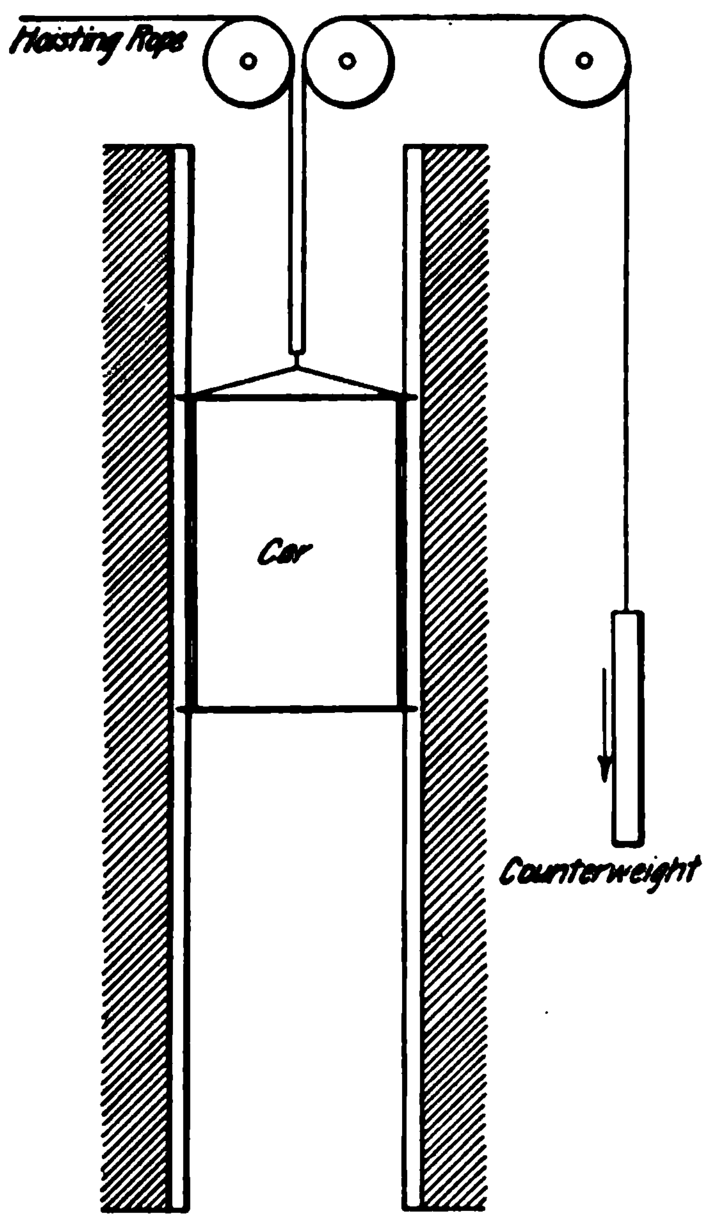


FIG. 6.

11. If in an elevator the power can be applied during the down trip as well as during the up trip, then not only the full weight of the car can be counterbalanced, but also a part of the load. An elevator thus counterbalanced is said to be **overbalanced.** This possibility exists in all drum elevators, as the motor and drum are reversible. They are, therefore, overbalanced, except when other considerations

make it undesirable, to the extent of the average load by attaching the counterweight to the drum and winding the rope in an opposite direction to that of the hoisting rope, as shown in Fig. 7.

The advantage of overbalancing is easily apparent. If the load in the car is equal to the average load, no power is

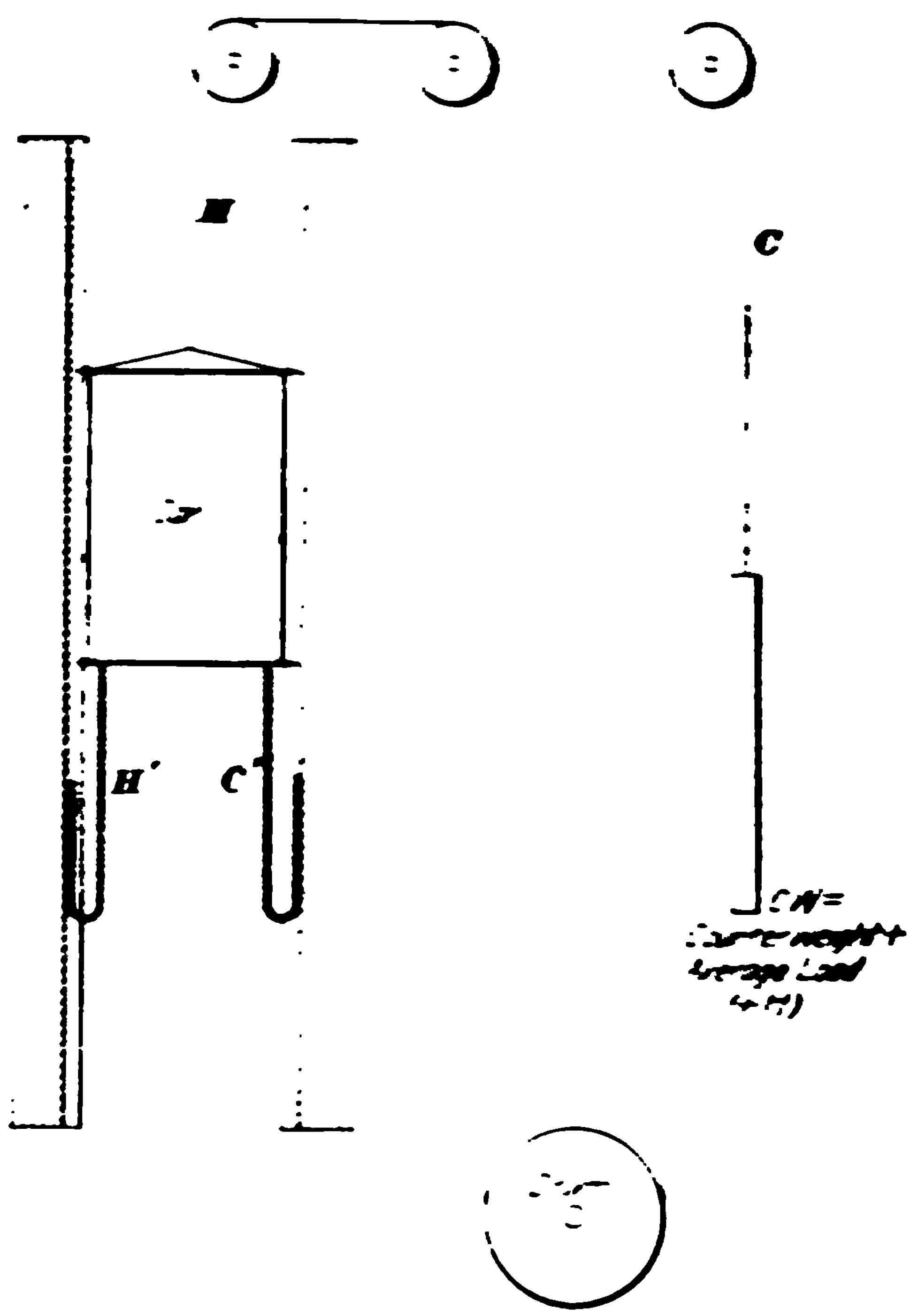


FIG. 7.

needed besides that necessary to start the machinery and keep it moving against frictional resistances. If the load is equal to the maximum load and the car is going up, the motor must furnish power enough to raise the difference between the maximum and the average load; or if the latter is one-half the maximum load, to raise one-half of the maximum load. If the car is going down empty, which is the

other extreme possibility, the motor must raise the counterweight, that is, the weight of the average load. Thus a motor can be used of greatly smaller capacity, which means smaller size, less weight, and smaller cost. In connection with electric drum elevators, overbalancing also tends to equalize the current consumption.

12. By an arrangement somewhat different from that shown in Fig. 7, the stress in all the ropes and the pressure on the drum-shaft bearings may be diminished. In Fig. 8

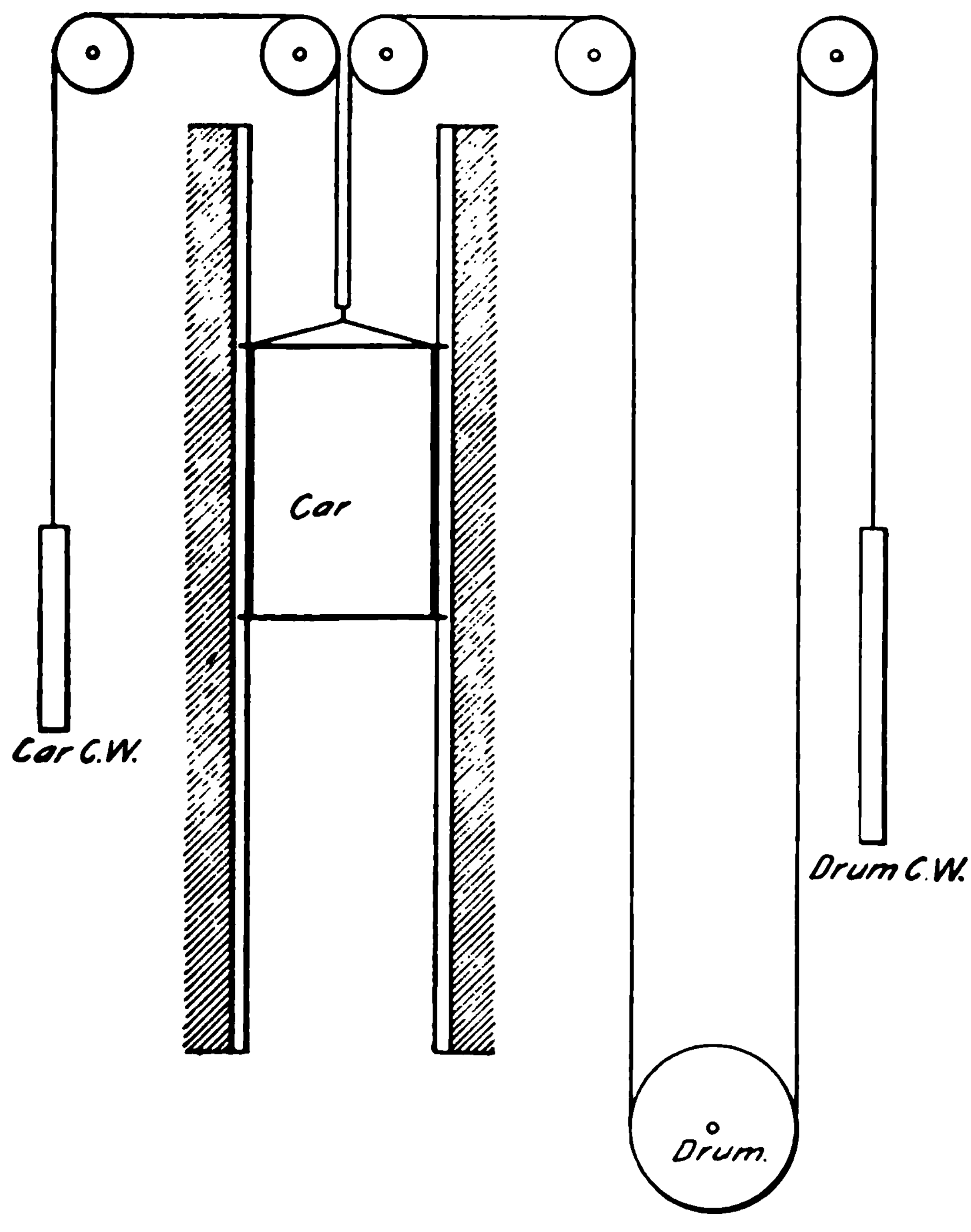


FIG. 8.

there are shown two counterweights, one attached directly to the car and the other to the drum. The car counterweight must evidently be less than the weight of the car in

order to allow the car to descend when empty; the other counterweight is equal to the remaining portion of the car weight plus the average load. If the car counterweight is, for instance, one-half of the car weight, then the stress in the drum-counterweight rope and the hoisting rope is less than in the arrangement shown in Fig. 7 by one-half of the weight of the car, and the pressure on the drum-shaft bearings is less by the whole weight of the car.

13. For high lifts, the weight of the ropes themselves is a considerable item, making the counterbalancing change for different positions of the car. To avoid this, balancing chains having the same weight as the ropes to be balanced are used and are hung from the bottom of the car, either reaching all the way down to the bottom of the hoistway, in which case the chain must have the same weight per unit of length as the ropes, or reaching down only to the middle of the shaft and fastened there, in which case the chain must have a weight per unit of length double that of the ropes to be balanced. This method is indicated in Fig. 7.

The ropes to be balanced here are the hoisting rope from the car to the overhead sheave and the counterweight rope from the counterweight to the overhead sheave, denoted, in Fig. 7, by H and C, respectively. The former can be balanced by a chain H' of equal weight and an increase of the counterweight by the same amount, while the rope C can be balanced simply by a chain C'. Of course, two chains would be actually used, each weighing $\frac{H+C}{2}$.

14. All counterbalancing means an addition to the moving masses of the elevator, which, again, means an increase in the power required to set these masses in motion, as well as greater braking power to stop them. These considerations make it desirable in certain elevator types to forego the advantages of overbalancing.

COUNTERBALANCE WEIGHTS AND GUIDES.

15. The **counterweights** consist generally of cast-iron blocks carried in a frame or on a rod or rods and guided by suitable guideways. The blocks are made long and wide, but thin, in order that they may take up but little room. In hydraulic elevators the counterweights are sometimes attached to the piston rods, either inside or outside of the hydraulic cylinder.

The counterweight guides are made of angle or **T** iron, seldom of wood.

CONTROLLING DEVICES.

16. Kinds of Controlling Devices.—The controlling devices of all elevators consist of a **power control,** that is, means for shutting off, turning on, and regulating the power at will to start and stop the car, and some kind of a **brake,** the function of which is to effect a prompt but gradual, and therefore safe, stoppage of the car.

The power control and brake are essential parts of the motor in each case and are, therefore, located near the same; they are naturally different for different kinds of motive power, and will be described at length in connection with the various types of elevators. There is, however, with respect to the controlling devices a certain feature common to all.

Since most elevators are operated from the movable car, some flexible connection must exist between the same and the controlling devices on the motor. The means for making this connection, which we will call **operating devices,** are either mechanical or electrical. The latter is used to any extent only with a certain kind of electrical elevators, while the mechanical connection is employed on all types in the shape of a **shipper rope** running all the way from the top to the bottom of the hoistway and either simply passes through the car or is connected with some apparatus inside the car.

17. Different Operating Devices. — The simplest arrangement is a plain endless rope hung over one or more idlers and attached to the shipper sheave or a lever, so that a pull either up or down on the shipper rope moves the sheave or lever, which is located on or near the motor and is mechanically connected to the controlling devices of the same. This simple arrangement, which is shown diagrammatically in Fig. 9, is open to several objections, one of which makes its use undesirable in connection with all motors requiring a delicate adjustment of the controlling device, such as hydraulic motors controlled by a pilot valve and electric motors, inasmuch as the operator has no means of telling the exact position of the controlling device. Another objection is that there is necessarily a great deal of sliding of the rope through the hand of the operator, which is not only inconvenient, but may prove dangerous from broken strands. The operator should provide himself with a leather glove or use a piece of rubber hose split lengthwise.

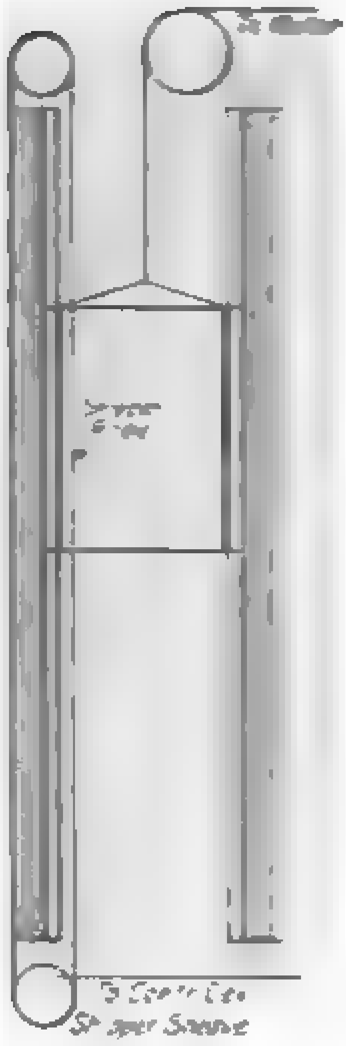


Fig. 9.

18. In order to overcome the objections to the simple shipper rope, various devices have been invented and put into use. They all have the object of changing the up-and-down pull of the rope into the motion of a lever or crank. In Figs. 10 to 16 are shown a number of these devices as actually used, particularly in connection with hydraulic elevators. In the arrangement shown in Fig. 10, there is a three-armed lever A in the car, the long arm of which is to be swung to the right or left by the operator. To each of the short arms is connected a rope R running down over an idler carried by another three-armed

lever *B* pivoted at the bottom of the hoistway. From the idlers on lever *B* the ropes *R*, *R* pass up again and over idlers fixed at the top of the hoistway, as shown. On the ends of the ropes are counterweights which are equal, and each is somewhat heavier than the equivalent force necessary to move the controlling device of the motor, which is mechanically connected to the third arm of the lever *B*. As will be easily understood, the whole arrangement is in equilibrium in any position of the lever *A*, but the equilibrium is disturbed as soon as a pull is exerted on it in either direction, in consequence of which the second lever *B* will follow the motions of *A* and stay in a position corresponding to that of *A*. The top idlers are shown in the diagram on separate shafts or studs; in reality they are placed side by side and the downward rope passed through the counterweight nearest to it, as shown in Fig. 10 (*a*). The weight is thus guided on the rope. To prevent abrasion of the rope, a rubber ring is inserted in the hole through the weight.

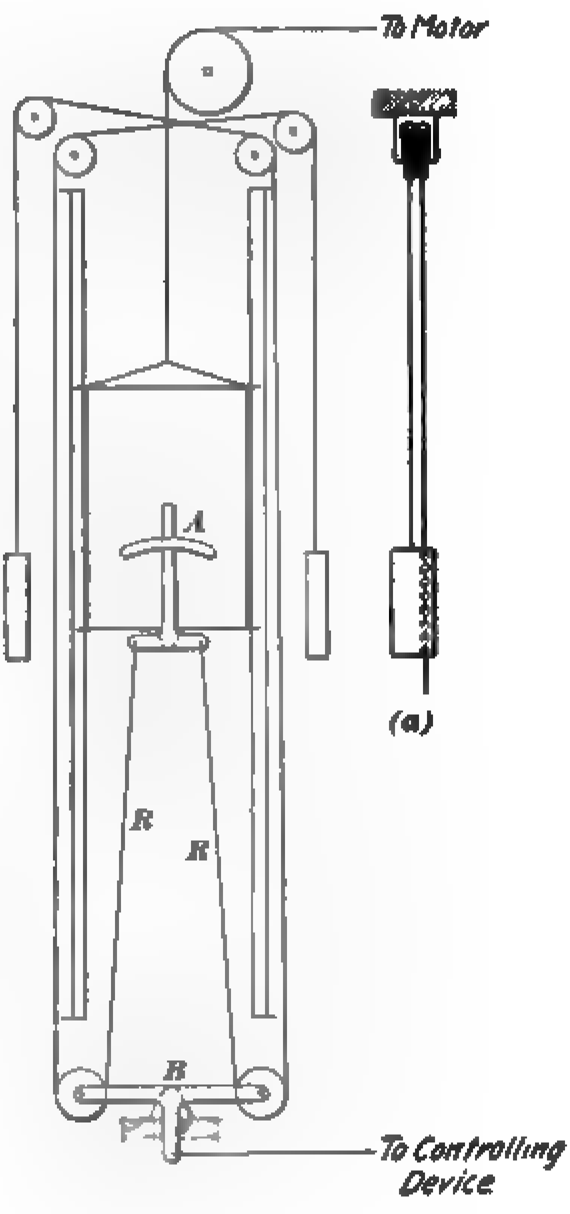


FIG. 10.

19. Another arrangement is shown in Fig. 11. The shipper rope is led from a fixed point *a* at the top of the hoistway over two idlers *b* and *c* mounted on a lever *L* pivoted to the car and handy to the operator. From the idlers *b* and *c* the rope is carried farther down, around

the shipper sheave S, and thence back upwards over two more idlers c' and b', also attached to the lever L, and is finally fastened at the top at d. While the car moves

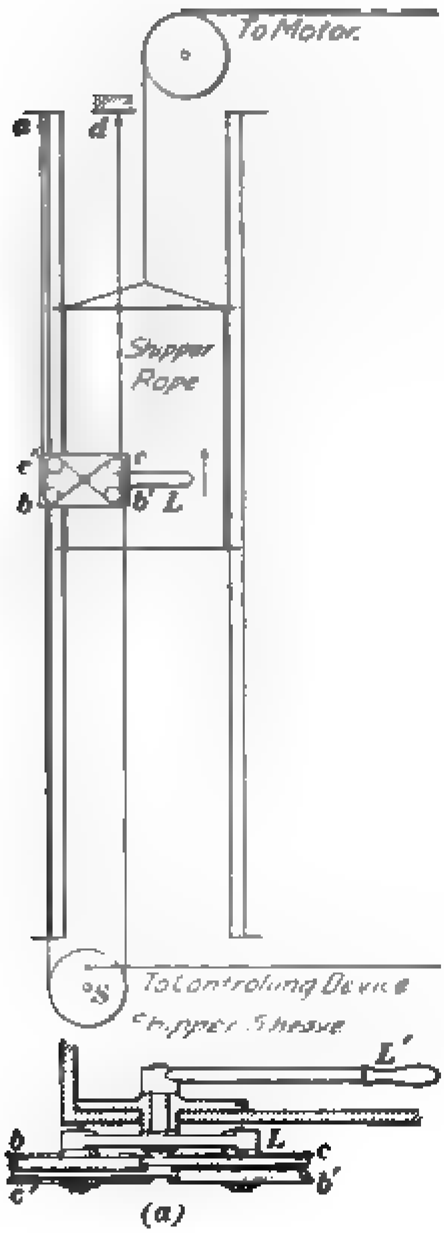


FIG. 11

up and down, the shipper sheave S is stationary unless the lever L is moved. By moving L upwards, the part $b\ c\ S$ of the rope is doubled up more, while the part $b'\ c'\ S$ is straightened out an equal amount, causing the sheave S to take a position depending on that of the lever L, in which position it remains until the lever is moved again. In an actual machine the idlers are mounted on studs, b and c' on one stud and b' and c on another stud, which are carried on a lever outside the car; the pivot of the lever is carried through into the interior of the car, where it carries the handle L' [see Fig. 11 (a)]. A hand wheel may be substituted for the handle L'.

20. The same idea that underlies the arrangement of Fig. 11 is embodied in Fig. 12. Here the two branches of the rope are deflected so as to pass over two idlers i, i' on the same stud and are attached to a lever pivoted to the car; the other idlers a, b, c, and d are fixed to the car.

21. The devices shown in Figs. 11 and 12 necessitate idlers to be carried on the car, where they must, owing to the limited space available, be necessarily small. This detrimental to the rope, especially since it is bent in osite directions in quick succession. These objections

do not prevail in the arrangement shown in Fig. 10, where the idlers may be ample in diameter and the ropes are bent in one direction only.

22. An improvement on Fig. 12 is the operating device shown in Fig. 13, in which the ends of the ropes are attached to the car instead of to moving weights; a single

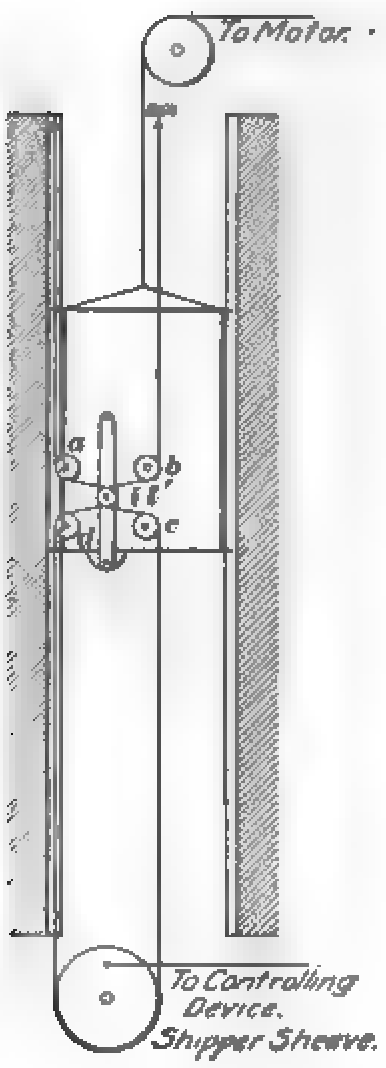


FIG. 12.

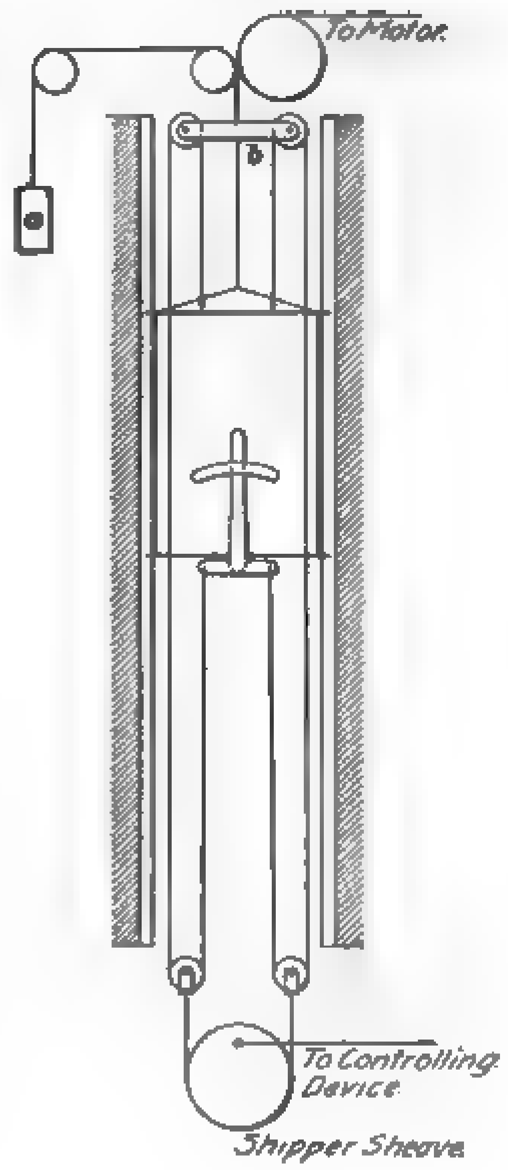


FIG 13.

stationary weight *a* attached by a rope to a cross-bar, or frame, *b* carrying the upper idler is substituted for the moving weights.

23. This arrangement has been still further improved upon in the manner shown in Fig. 14. The ends of the

ropes that were attached to the car in Fig. 13 are here also attached to the lever arms, and the two ropes leading from the lever of the two idlers are crossed. It can easily be seen that by this means the motion of the lever gives twice as much motion to the sheave as in the arrangements shown in Figs. 10 and 13.

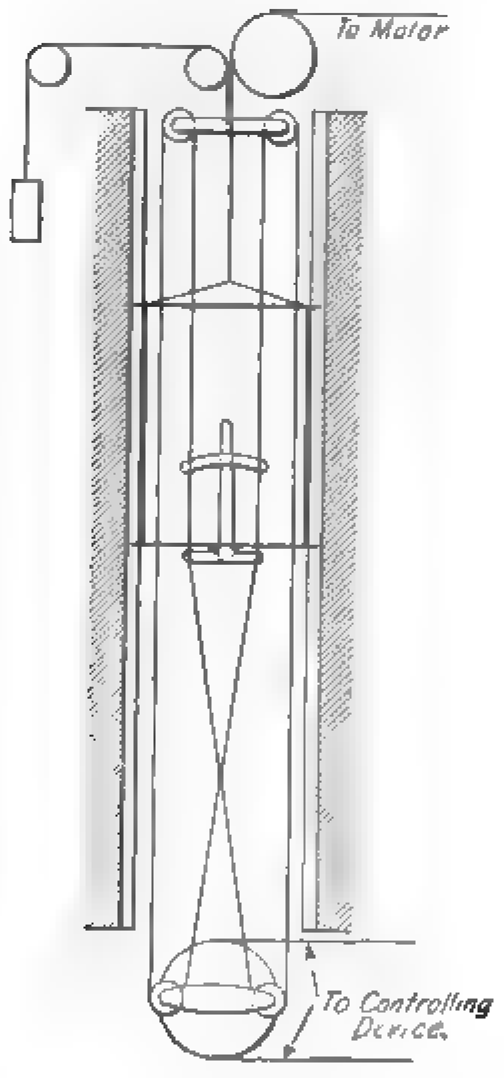


FIG. 14

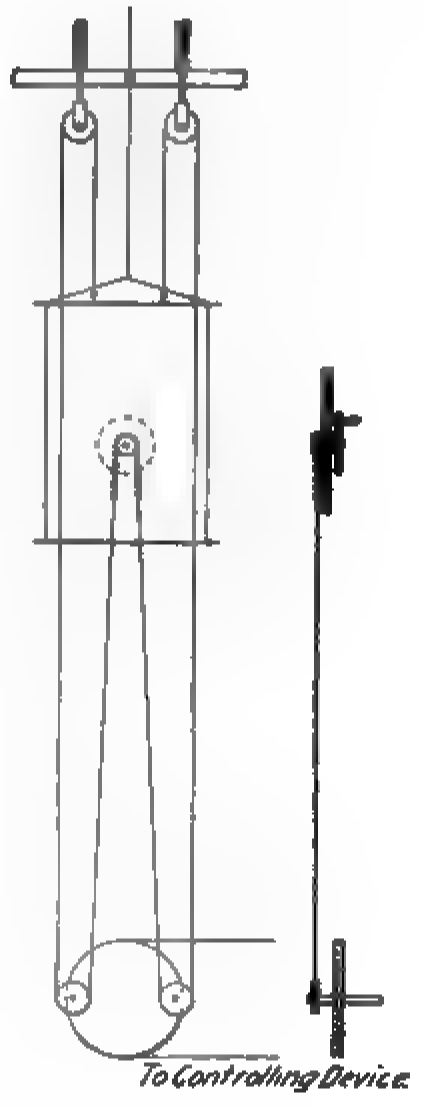


FIG. 15.

24. The operating device last described is known as the **Otis lever, or operating device,** and is now used almost exclusively on the hydraulic elevators of the Otis Elevator Company. By substituting a hand wheel or crank for the lever in Fig. 13 and attaching the lower idlers to the shipper sheave, a modification shown in Fig. 15 is obtained that is found on a good many elevators of the Otis make and is called a **hand-wheel operating device.** By elevator

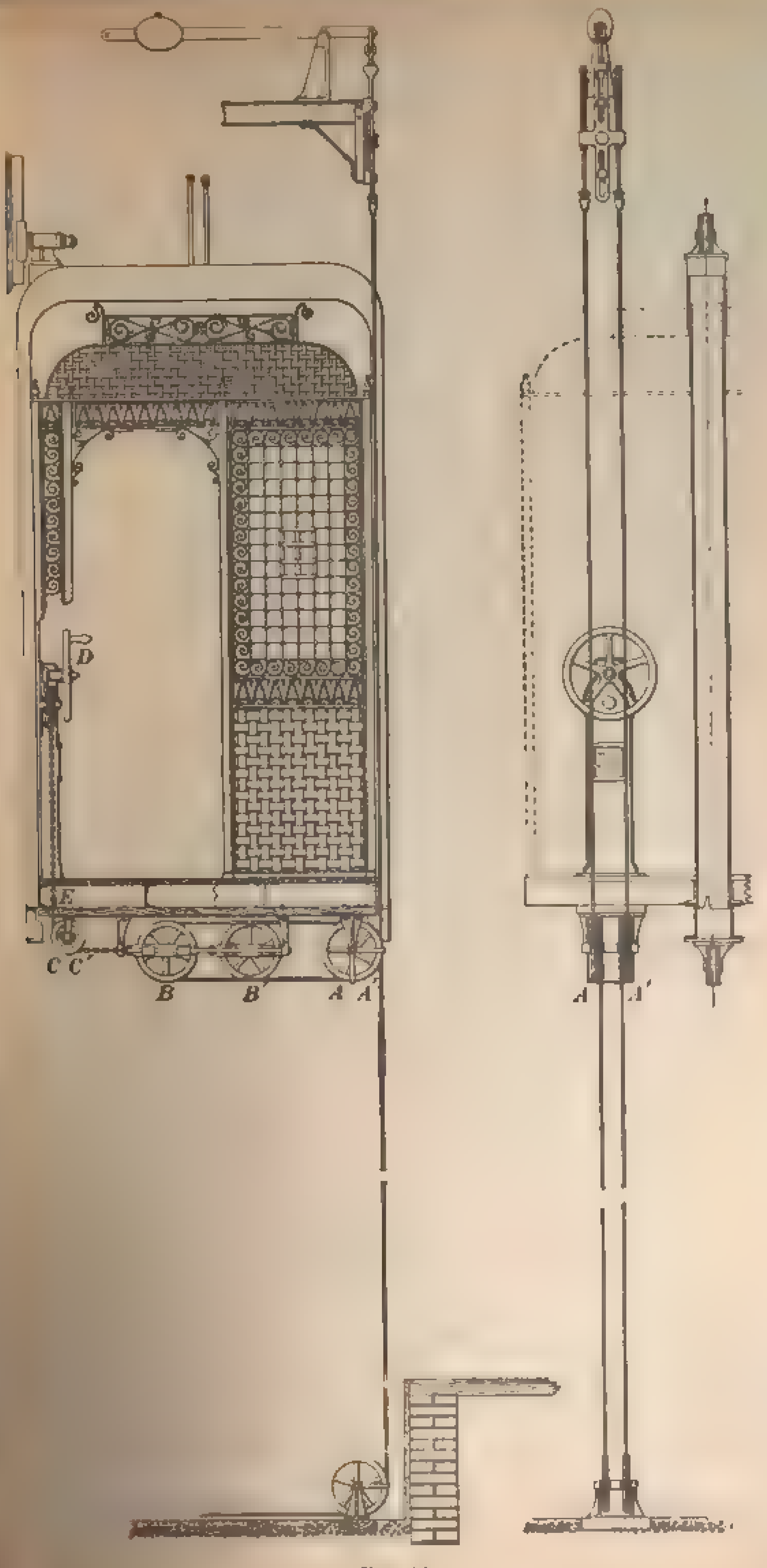


FIG. 16

runners the operating devices are often called **controllers** and are spoken of as **lever controllers, hand-wheel controllers,** etc. Since the term *controller* is also given to the combination of switches and resistances constituting the controlling device proper in electric elevators, the practice just mentioned is not followed here in order to prevent confusion.

25. A common arrangement of a hand-wheel operating device is shown in Fig. 16. The sheaves A, A' are stationary, but the sheaves B, B', being loosely mounted on guide rods, can be shifted by means of the hand wheel D and chain E. The chain runs over the wheels C, C'. After the explanations of the operation of the different operating devices that have been previously given, the operation of this one will be easily understood.

SAFETY DEVICES.

26. We can divide the **safety devices** used on elevators into two distinct classes: those that control the power supply, which we shall call **motor safeties**, and those that control the car independently of the power supply, which we shall call **car safeties**. The former must necessarily be treated in connection with the various styles of motors used; the latter admit, and their importance warrants, a treatment by themselves, which will be given in its proper place.

ACCESSORIES.

[illegible] accessories we shall class all those various [illegible]ed to prevent accidents from causes other th[illegible] its parts, and to [illegible] and the effi[illegible]ances are auto[illegible] signals, indicators, etc.

HAND-POWER ELEVATORS.

CONSTRUCTION.

28. When an elevator is to be used but little, and especially if speed of the car is not essential, it does not pay to use steam or other motive power; **hand-power elevators** are then useful. With few exceptions they are installed for freight service only.

Figs. 17, 18, 19, and 20 show several types of hand-power elevators. Those shown in Figs. 18 and 19 are made by Morse, Williams & Co., of Philadelphia, Pennsylvania, and those shown in Figs. 17 and 20 by the A. B. See Manufacturing Company, of Brooklyn, New York.

29. Motor.—The *motor* of a hand-power elevator is represented either by a shaft actuated through a rope sheave and endless rope, the latter being pulled in either direction by hand, and examples of which are shown in Figs. 17, 18, and 19, or it is represented by a crank driving a windlass, as shown in Fig. 20.

30. Transmitting Devices.—The *transmitting devices* consist of spur gearing in connection with either a drum for a rope or chain, as in Figs. 17, 19, and 20, or a friction sheave, as in Fig. 18.

31. Operating Devices.—The *operating device* is a manila rope, preferably a four-strand and "stevedore" rope; the hoisting and counterweight ropes are generally wire ropes. In the sidewalk elevator shown in Fig. 20, chains take the place of the rope.

32. Cars.—The cars in Figs. 19 and 20 are different from the ordinary cars, inasmuch as they are supported on all four corners.

Small hand-power elevators are used largely for carrying small loads in dwellings, restaurants, libraries, etc., and are called **dumbwaiters.** The cars of these then take the shape of a box with or without shelves.

33. Guides and Counterweight.—In the elevator shown in Fig. 19 *guides* are provided on one side only. The *counterweight* in Fig. 17 is hung from a separate drum,

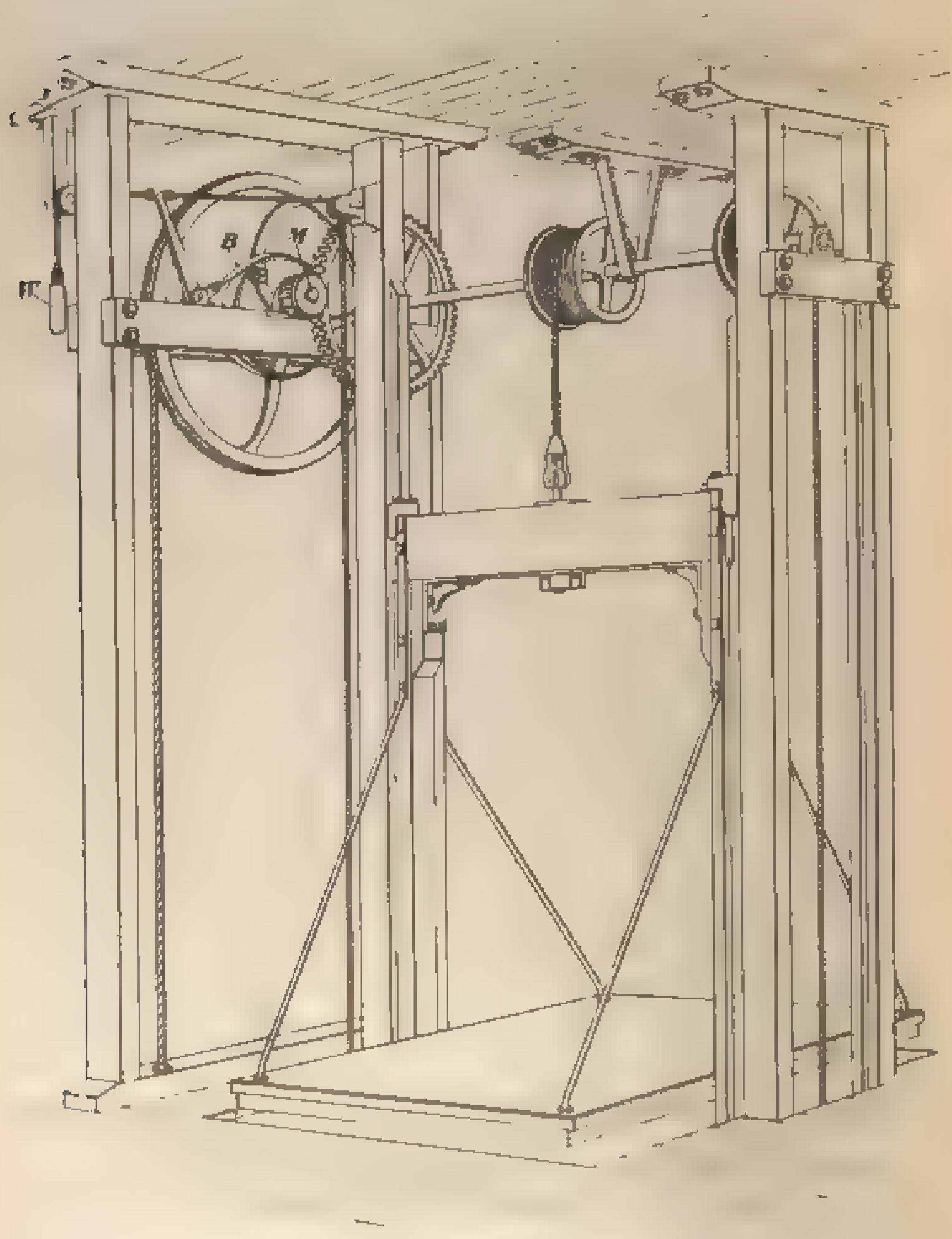


FIG. 17

in Fig. 19 it is hung from one of the hoisting drums; in Fig. 18 it is attached to the other end of the hoisting cable; and in Fig. 20 the counterweight is dispensed with entirely.

When hand-power elevators are balanced, they are generally overbalanced.

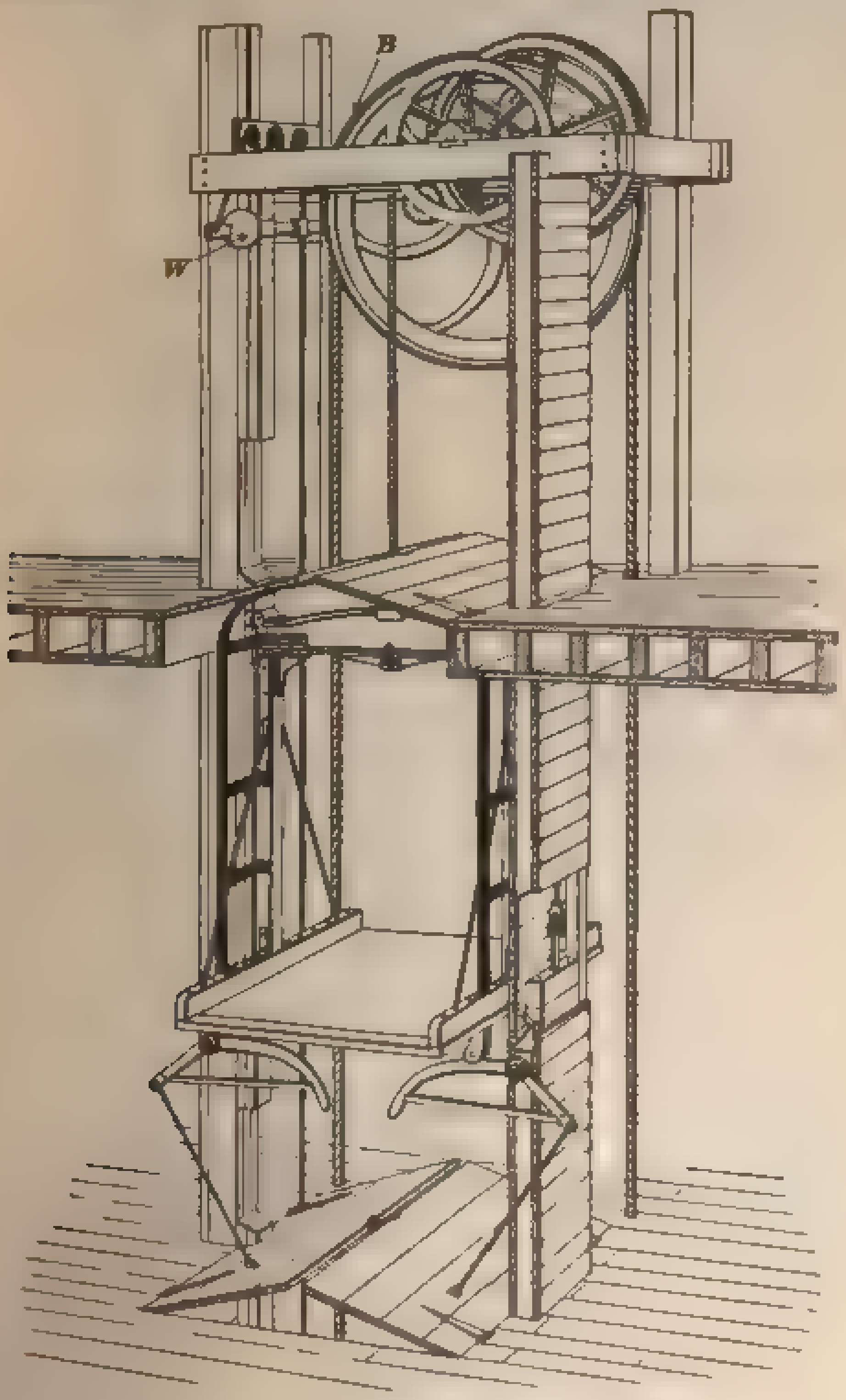


FIG. 18

34. Controlling Devices.—The *controlling device* in Figs. 17, 18, and 19 consists only of a brake *B*, which is applied by a weight *W* and is loosened by the operator by means of a hand rope. In the windlass, or winch, type of elevator,

shown in Fig. 20, the brake is actuated, both in applying and loosening it, by operating the lever L by hand. Since

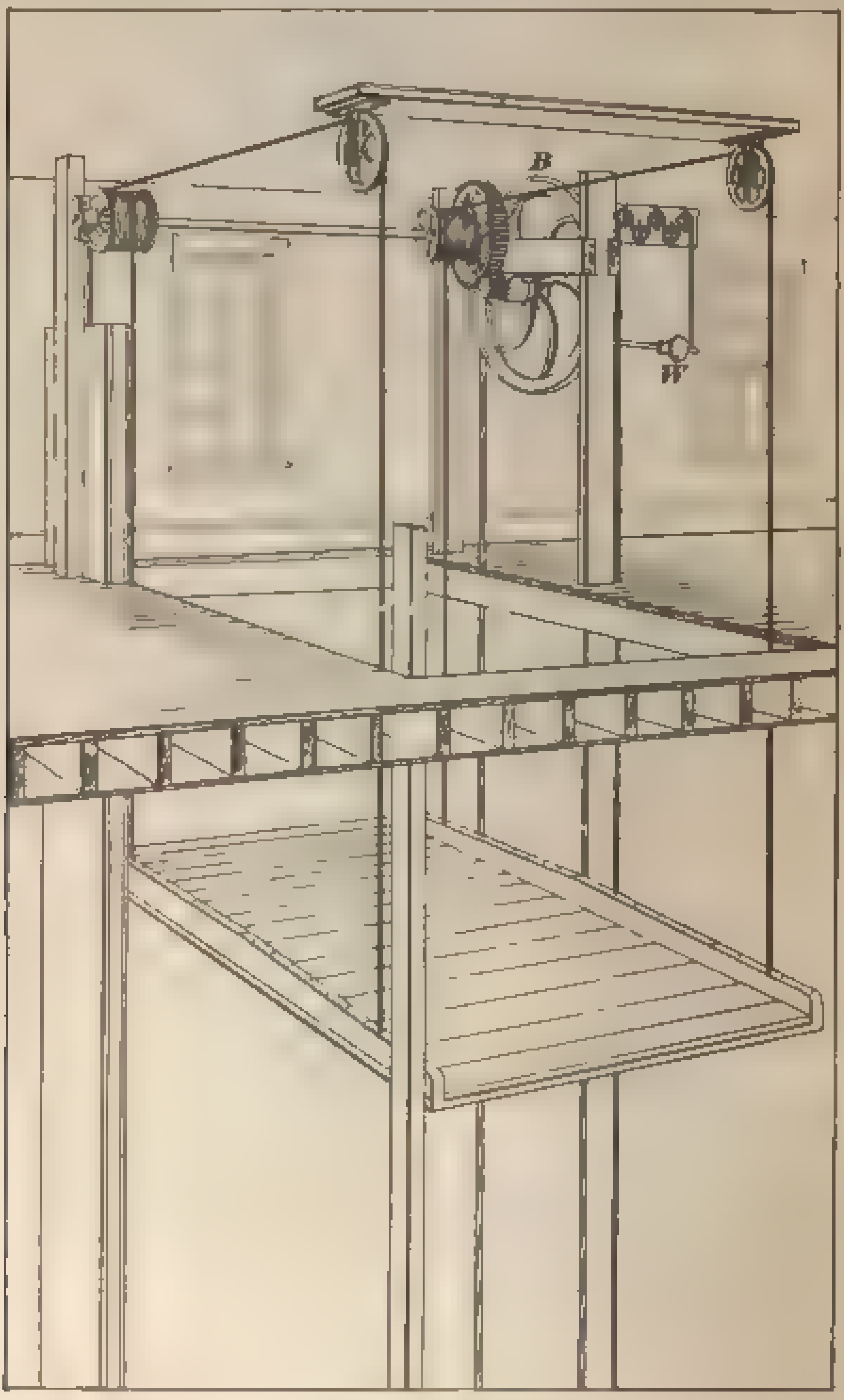


Fig. 19.

the brake is not applied automatically, a pawl P is thrown in mesh with the gearing when the elevator is at rest.

35. Motor Safeties. Hand-power elevators have no *motor safeties*.

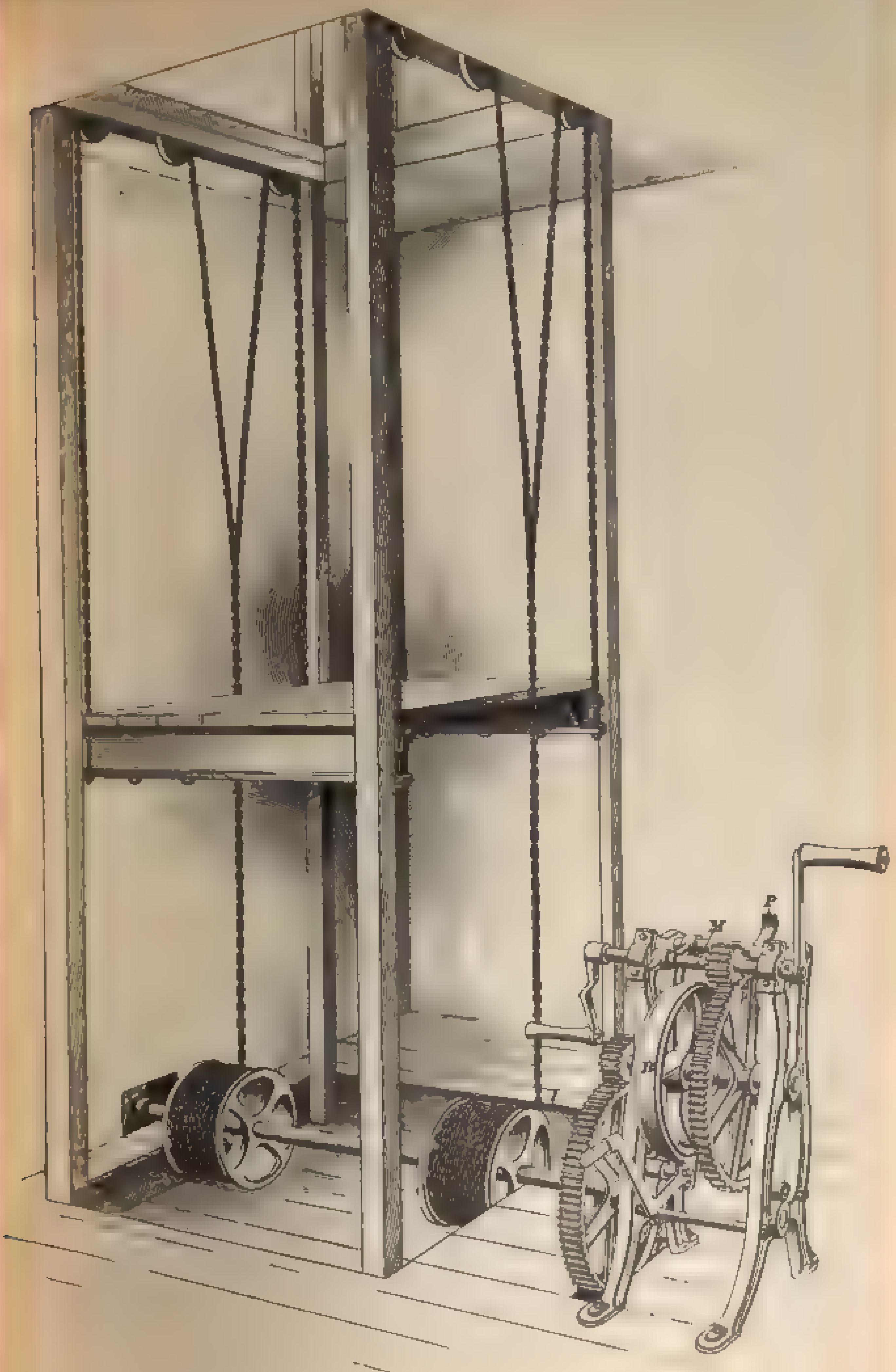


Fig. 20.

OPERATION AND MAINTENANCE.

36. The mechanisms of hand-power elevators are so simple that any one can operate them without difficulty; nevertheless, no less care should be exercised in handling them than power-driven elevators. Carelessness and neglect will prove just as dangerous with hand-power elevators as with any other type.

37. Hand-power elevators cannot be operated from the car, but are operated from any floor; a person riding on the same has no control over its movements and takes considerable risk. In operating, the operator lifts the brake and pulls the hand rope. In the design shown in Fig. 17, he must hold on to the brake rope, or **check-line**, as it is called, as long as the car is to move. This necessity is avoided by the arrangement shown in Figs. 18 and 19, the check-line passing over a number of small friction pulleys that give enough friction to the rope to hold the brake on or off after the operator has moved it by either an upward or downward movement of the hand. This device is a peculiarity of the hand-power elevators built by Morse, Williams & Co.

38. As the first and foremost rule it must be remembered that an elevator is built for a certain maximum load and that this load should never be exceeded.

39. All elevators should be started and stopped gradually. It takes more power to run an elevator up to a required speed than to maintain that speed thereafter; this additional starting power is the greater the shorter the time within which the necessary speed is attained, and the greater is also the stress in all parts of the machinery. Likewise, it takes considerable power to stop a moving elevator, which power is supplied by the braking device, and which is required to be the greater the quicker the elevator is stopped. Thus, if an elevator is stopped too quickly, enough stress may be put on the braking device to destroy it, causing accident. In hand-power elevators there is hardly any danger from quick starting, but there is from a sudden application of the brake, especially if the elevator

is underbalanced and, as is often done, allowed to attain considerable speed in descending.

40. The drums, sheaves, and gears should be frequently inspected as to their fastenings to the shaft.

41. The brake needs particular attention, as the safety of the elevator depends on it.

42. If any car safety is provided, as there should be, the same should be examined frequently and carefully until the operator is satisfied that it is in good working condition; its parts should be kept well oiled and *should be kept clean*, to avoid their sticking and refusing to act in case of an emergency.

CARE OF WIRE ROPES, CABLES, AND GUIDES.

43. All that is said in Arts. **44** to **51** applies to all elevators, inasmuch as in all of them wire rope is used more or less and all have guides.

44. The wire ropes used in elevator work are made with hemp centers, to make them more pliable and thus more durable, on account of the short bends over comparatively small pulleys, or sheaves. Galvanized rope should not be used; the thin coating of zinc soon wears off, leaving the wires exposed to rapid deterioration by corrosion.

45. The wire ropes should be examined often and carefully; hoisting cables should be condemned as dangerous when the *wires* (not the strands) commence cracking. Wire ropes used for hoisting should under no circumstances be spliced.

46. Wire rope must be handled much more carefully than hemp rope, inasmuch as it is liable to kink and twist, which must be avoided on account of the harmful effect. Wire rope is best mounted on a reel that can be placed on a spindle to pay out the rope. If received from the supply house without a reel, the rope should be paid out by rolling the coil over the ground like a wheel. Wire rope should be lubricated like other moving machinery parts to preserve it.

To prevent rusting, raw linseed oil should be used and applied with a piece of sheepskin. The J. A. Roebling Sons Co. recommend to mix the linseed oil with the equal parts of Spanish brown or lampblack The Otis Elevator Company recommend a mixture of 7 parts of linseed oil and 3 parts of tar oil. Another good preserving lubricant is made by heating and mixing well cylinder oil, graphite, tallow, and vegetable tar When the **ropes,** or **cables,** as they are called frequently in elevator work, have once become well soaked, they need oiling only about every third or fourth month. They should not be allowed to become dirty and gummy.

47. In replacing worn ropes, particular attention must be given to the fastenings. In all cases where the ropes are replaced for the first time, it is best to carefully reproduce the joint as it was originally made by the makers or installators. An engineer taking charge of an elevator plant will, however, sometimes find rope fastenings of an inferior kind made by his predecessor. It may, therefore, be in order to call attention to the principal methods used by manufacturers.

48. The **shackle** used by the Otis Elevator Company is shown in Fig. 21. It consists of a split rod, the two legs *A*, *A* of which are bulged out and provided with noses at the ends. A collar *B* straddles the legs and eventually abuts against the noses. The rope is brought through the collar, bent over a **thimble** *C*, and passed back again through the collar, after which the free end is fastened by wrapping with wire. The wrapped end of the rope should be at least 8 inches long. The inside surfaces of the legs *A* and the outside surface of the thimble are concave to conform with the rope. Instead of the wire wrapping, clamps are sometimes used; the wrapping is to be preferred, however.

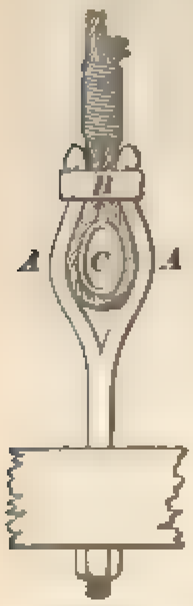
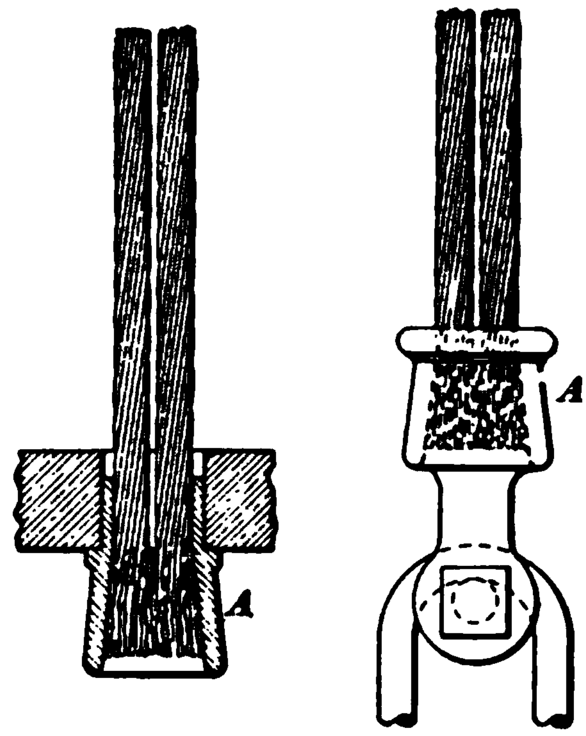


FIG. 21

49. Another fastening is shown in Fig. 22. The rope is passed through a socket *A* forming part of the shackle; then it is untwisted for a short distance and the individual

wires bent double. The socket is then filled with molten lead, or, better, with Babbitt metal, which should be of the best quality. The sockets should be warmed before the metal is poured to prevent chilling.



(a) (b)

FIG. 22.

50. In fastening the rope to the drum, it must be observed that at the lowest position of the car the rope must still encircle the drum several times to reduce the stress at the point of fastening.

51. The guides should not be allowed to become gummy and should, therefore, be cleaned from time to time—about twice a month—and freshly lubricated. Gummy guides cause the car to alternately stick and free itself, making its motion jerky; and a bad case of sticking may cause the car to drop a distance great enough to break the cable and thus cause serious accident. In cleaning guides, a judicious occasional use of kerosene oil is recommended. For a lubricant on steel guides good cylinder oil is used; some use a composition that is seven-eighths cylinder oil and one-eighth plumbago, well mixed. Wooden guides are greased with No. 3 Albany grease or lard oil; a mixture of tar oil and wax is also recommended by some.

BELT ELEVATORS.

DEFINITION.

52. The term **belt elevator** is applied to that class of elevators that are driven directly by belts from line shafting, which shafting, in turn, may be driven by any prime mover and may be used for driving other machinery at the same time. Belt elevators are used for freight service principally, seldom for passenger service.

INSTALLATION.

53. The shaft from which the power is taken revolves

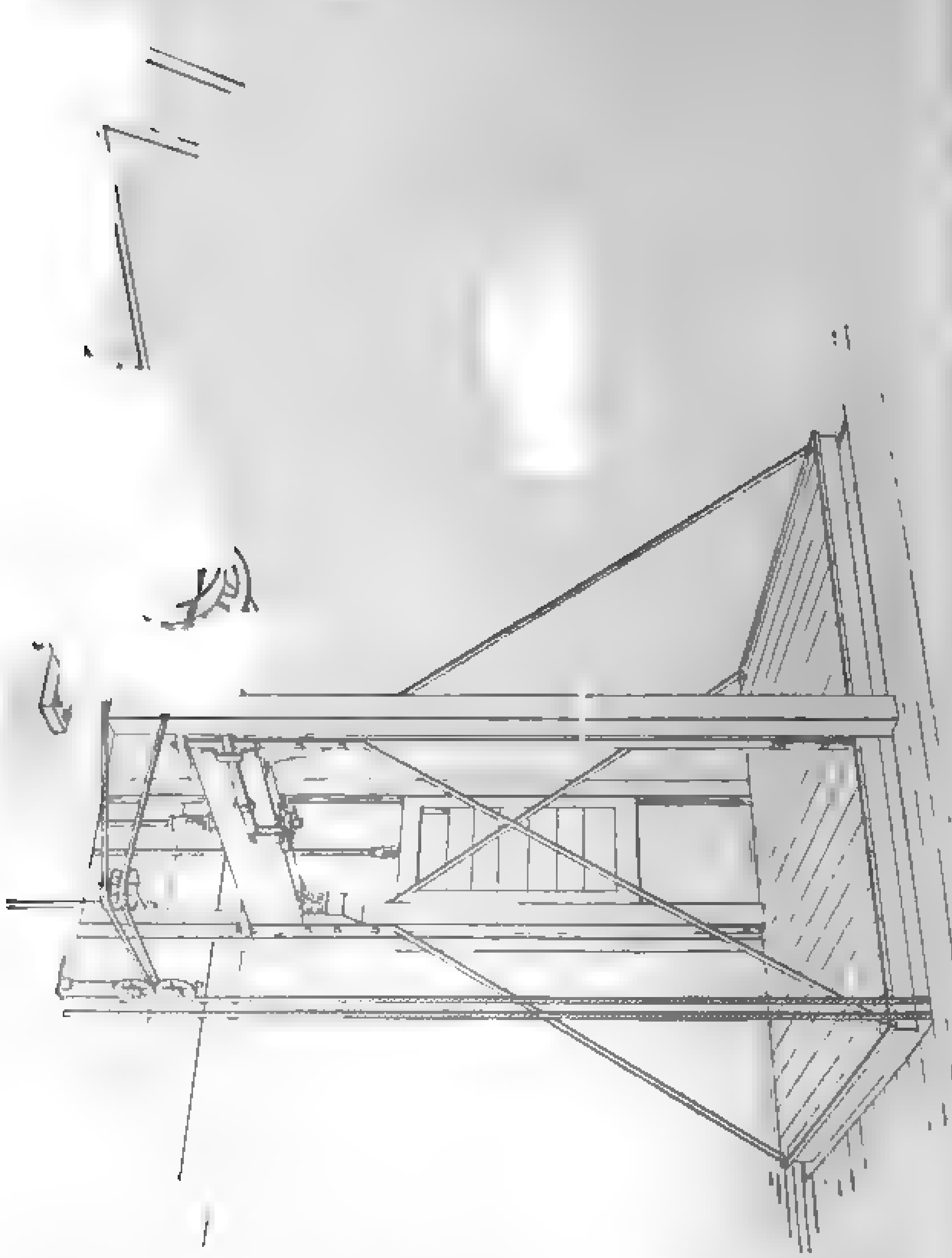


FIG. 28

continuously in the same direction independently of the motion of the elevator—that is, uncontrolled by the

operator. The power is transmitted from this shaft to the elevator machine either direct, if the shaft is conveniently located, or by a countershaft. In either case, the shaft or countershaft carries a wide pulley that drives two belts, an open one *a*, Fig. 23, and a crossed one *b*. The elevator machine *c* is preferably placed on the ceiling, as shown, to save floor space, but it may be put on the floor as well. In many cases it will be possible to place it directly over the hoistway and thus save the expense of overhead sheaves.

GENERAL DESCRIPTION OF PARTS.

54. Following up the various parts again in the order named in Art. **2**, they present themselves as follows:

The *motor* of a belt elevator is simply a shaft carrying two loose pulleys and one tight pulley; it is designated by *M* in the various illustrations following hereafter.

The *transmitting devices* consist of either worm-gearing or spur gearing connecting the shaft *M* with the drum, worm-gearing being by far the more common arrangement.

When *counterbalancing*, worm-geared belt elevators are generally overbalanced; spur-geared ones are not. The reason for this is that worm-gearing works much smoother than spur gearing; it starts and stops gradually, offering much more resistance during the period of getting up speed, and acts as a kind of brake by itself in bringing the elevator to rest. The addition to the moving masses due to overbalancing, therefore, greatly increases the jerkiness of motion in spur-geared machines, while it has little influence that way in worm-geared ones.

The *controlling devices* consist of a pair of belt shifters, constituting the power control, and a brake, both being operated simultaneously by a shipper rope.

CONSTRUCTION OF CONTROLLING DEVICES.

55. In a belt elevator the controlling devices must be constructed in such a manner that the following requirements are fulfilled:

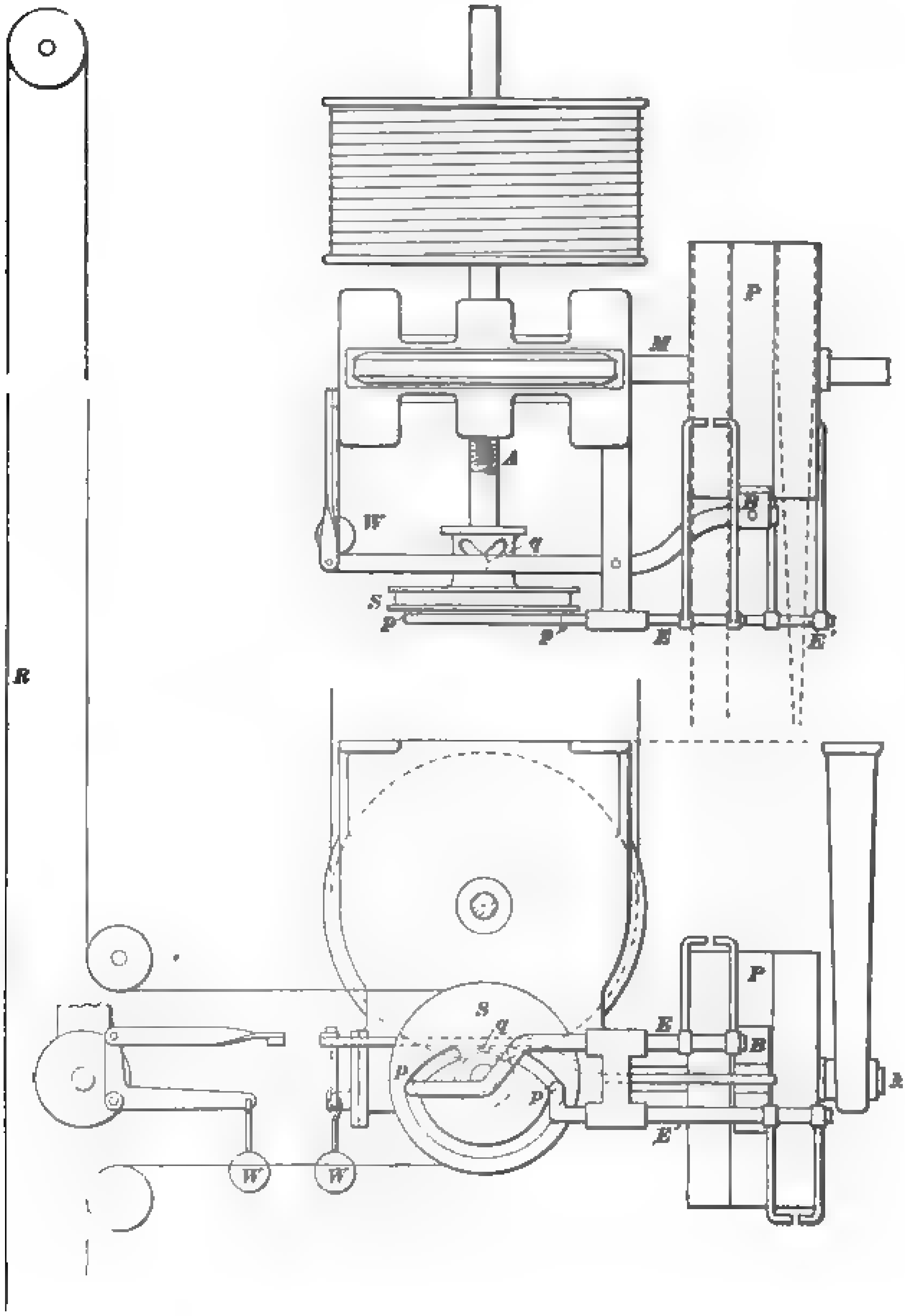


FIG. 24

(*a*) When the shipper sheave is in the central position, both belts must be on their respective loose pulleys and the brake must be *on*.

(*b*) When the shipper sheave occupies the extreme right- or left-hand position, one belt must be on the tight pulley, while the other must be on its loose pulley, and the brake must be *off*.

(*c*) In their respective driving or non-driving positions, the belt shifters must be locked in place, so that they cannot be accidentally shifted.

(*d*) It must not be possible to throw the shipper sheave over too far.

(*e*) The central position of the shipper sheave must be distinctly defined, so as to give the operator warning against overthrowing the sheave from the one extreme position to the other. It is evident that this danger always exists.

56. The requirements stated in Art. **55** are met in various ways in practice. Fig. 24 shows in a diagrammatical way a typical arrangement for this purpose. The figure does not represent an actual machine, but was prepared to show the various elements of a belt elevator, separately explaining their functions. The shipper sheave S has two cam grooves into which enter corresponding pins p, p' on the ends of the belt shifters E, E'.

The cam groove, it will be noticed, has one concentric middle portion and two eccentric side portions.

When the sheave is in a central position, as shown, both belts are on their respective loose pulleys. A pull downwards on the shipper rope R swings the shipper sheave around to the left; the pin p of the left-hand belt shifter enters the left-hand eccentric portion of the cam groove and is thus forced to the right, while the other pin p' travels in the concentric portion of the groove and thus remains stationary. The open belt is thus shifted on to the tight pulley P while the crossed belt remains on its loose pulley; the elevator car then ascends. On pulling upwards on the rope R, the reverse takes place and the elevator car descends.

On the hub of the shipper sheave a V-shaped cam groove is formed, into which enters a pin *g* in the middle of a lever that carries on the one end a brake shoe *B* and on the other a weight *W*, which latter is so connected to it by means of a system of links that it tends to keep the brake on the tight pulley; a swing of the sheave either to the right or left lifts off the brake. Thus requirements (*a*) and (*b*), Art. **55**, are fulfilled. Requirement (*c*) is met by the shape of the cam groove, and not only are the shifters locked to the sheave in whatever position the same may be in, but also while one shifter is being moved the other is held positively and immovably in place by virtue of the concentric position of the cam groove.

Requirement (*d*) is met by the proper length of the groove, and requirement (*e*) by the sharp corner of the V groove, which will make itself distinctly felt to the touch of the operator.

57. As already said, the simple shipper rope is used for an *operating device*, special devices, such as described in Arts. **18** to **25**, being uncalled for, owing to the comparatively slow speed of belt elevators and to the fact that the car begins to move only after the belt has been shipped a considerable distance, so that it requires but little skill to complete the shift during the accelerating period of the car.

MOTOR SAFETIES.

58. Limit Stops on Shipper Rope.—In all elevators that are run by motive power the danger exists, if no provision be made against it, that, through the operator failing to arrest the car on time, the car or counterweight may be hoisted against the overhead work, causing damage and accident. Such danger does not exist in hand-power elevators with their slow speed, the resistance immediately being felt by the hand when the car strikes an obstruction. It is, therefore, one of the provisos in every power-elevator design that the power be shut off and the car be automatically arrested at the limit of its travel up or down.

The means adopted for this purpose are called **limit stops**, and are of various designs. In all cases where a shipper rope passes straight through the car, knobs or buttons are clamped on the same, against which the car strikes when nearing its upper or lower limit of travel, thus operating the shipper sheave automatically. This means, of course, operates only as long as the shipper rope is intact. As it may easily occur that the shipper-rope connection is broken or the rope is otherwise ineffective, limit stops are also always provided on the motor itself.

59. Limit Stops on Motors.—For drum elevators the most common arrangement is that shown in Fig. 25. Let *A*

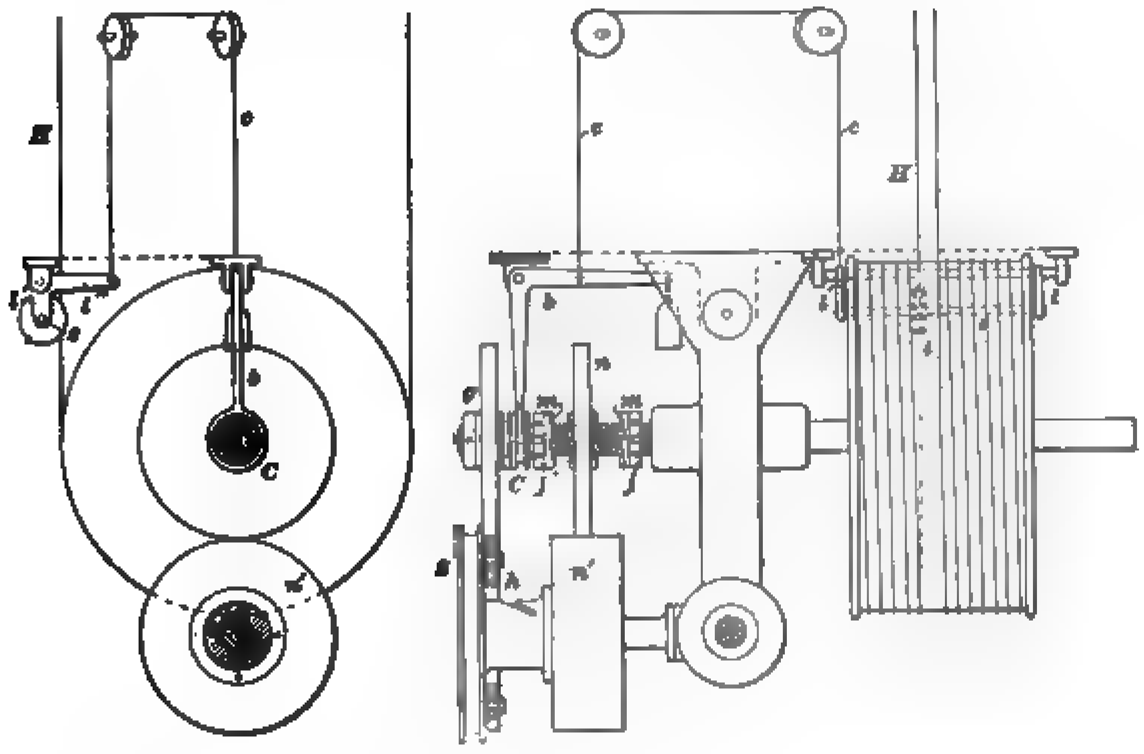


FIG. 25.

be a continuation of the drum shaft shown broken off in Fig 24. A screw thread is cut on this shaft and a gear-wheel *n*, the hub of which forms a nut, is placed on the threaded portion of the shaft; this gear-wheel meshes with another similar wheel *n'* bolted to the shipper sheave. It is evident that when the sheave is stationary and the drum rotates, the gear-wheel *n* will be prevented from revolving with the drum shaft, but will travel on the same in an axial direction either towards or from the drum, according to the

sense of rotation of the latter The hub of the wheel *n* has claws on either side, as shown, corresponding to similar claws formed on two other nuts *m* and *m* that are clamped by jam nuts *j* and *j'*, or in some other manner, securely to the drum shaft *A* Now, it will be easily understood that when the wheel *n* travels either way, it will eventually be engaged by either one of the revolving nuts *m* or *m* and be swung around, carrying with it the shipper sheave, with the effect of cutting off the power and applying the brake The nuts *m* and *m* can easily be adjusted to any position on the threaded portion of the drum shaft, and can thus be made to act when the car reaches the upper or lower limit in the hoistway.

SLACK-CABLE SAFETY.

60. Should the elevator car be obstructed in its descent by gummy guides or for any other reason and the motor continue to pay out the cable, the car would, if released suddenly, drop and most likely break the cable, causing damage; or should the car not drop, but be resting, for instance, on the bottom of the hoistway, the slack cable might still cause damage by getting into revolving parts of the machine In any case, if the hoisting cable becomes slack, it will quickly be riding over itself on the drum or otherwise get entangled and must be straightened out again, which entails much labor and annoyance. A frequent occurrence is a slack cable produced by a careless handling of the shipper rope It can often be noticed that when an operator in going up has missed his landing, he hastily reverses the machine to make his error good; the result is that the hoisting cable becomes slack. Now, most car safeties are so arranged that they will bind the car to the guides on the cables becoming slack In his perplexity at the sudden stoppage of the car, the operator is likely to forget to shift the shipper rope so as to stop the machine, and the latter goes on paying out rope Provision is made against such an emergency by contrivances called **slack-cable safeties.**

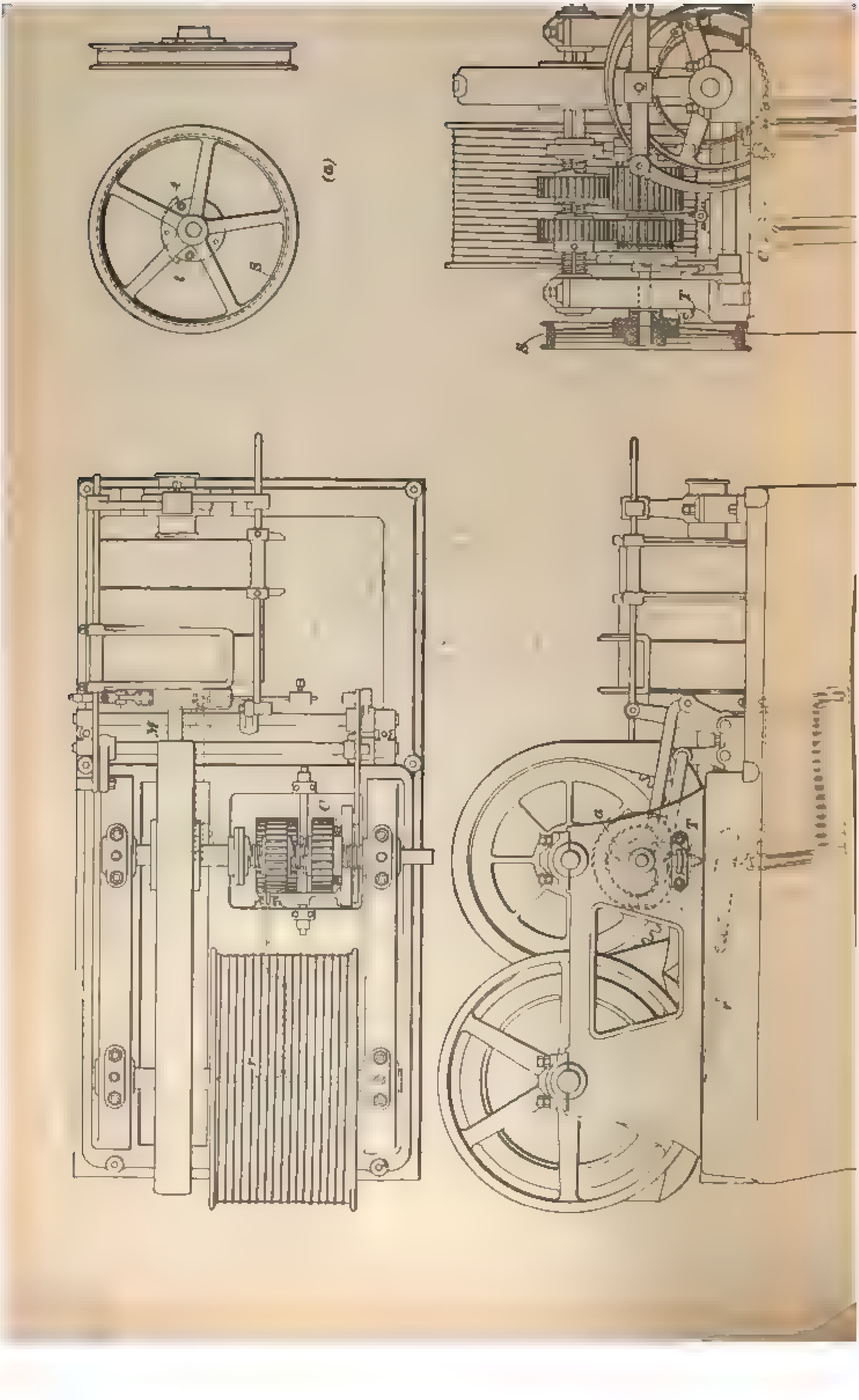
Fig. 25 shows the principle underlying such an arrangement: An idler *i* travels axially on its shaft *s* with the hoisting rope along the drum. The shaft *s* is supported on levers *l*, *l'* pivoted in a convenient manner. A cord *c* leads from the arm *l''* of the lever *l'* over sheaves to a bell-crank *b*, one arm of which is weighted, while the other engages a clutch *C*. As long as the hoisting rope *H* is taut, the idler *i* is pushed outwards against the weight on the bell-crank *b*; but should the hoisting rope become slack, the weight on the bell-crank *b* will cause the clutch *C* to engage with a gear-wheel *g* mounted loosely on the drum shaft, and will cause the same to revolve with the drum shaft. The gear-wheel *g* meshes with another gear-wheel *h* fastened to the shipper sheave, so that the latter will be swung around when the hoisting cable becomes slack.

61. The principles illustrated by Figs. 24 and 25 are found embodied in all belt elevators in various ways.

EXAMPLES OF BELT ELEVATORS.

62. Fig. 26 is a plan, elevation, and side view of a worm-geared belt-elevator machine built by The Whittier Machine Company, Boston, Massachusetts, and designed to be placed on the floor. While there is no particular difficulty about understanding the operation of the machine, a few explanations will nevertheless be in order. The machine has two worms, one left-handed and one right-handed, actuating two worm-wheels that mesh together. This combination prevents the end thrust, which is unavoidable in single-worm machines and saves the power necessary to overcome the frictional resistance due to it. There is, consequently, also no wear to the end of the shaft, and no step bearing is required, as in single-worm machines.

With regard to the controlling devices, it will be noticed that the belt-shifter cam groove is continuous. Special provision is, therefore, made against throwing the sheave over too far by fastening a stop-plate *T* to the frame, and



by stops t, t formed on the hub of the shipper sheave, as shown in detail in Fig. 26 (a).

The central non-driving position of the controlling device is made perceptible to the hand of the operator by nicking the brake cam, as shown in dotted lines at a in Fig. 26.

The limit stops are arranged practically in the same manner as in the typical drawing given in Fig. 25. The slack-cable safety is, however, radically different, inasmuch as the tension of the hoisting rope is not made use of; but, instead, the weight of one or more turns of rope hanging from the drum underneath in case the cable should become slack. For this purpose a rod r is placed across and underneath the drum, which rod is attached to the end of a weight-actuated lever that is tripped and closes the clutch C when there is any weight resting on the rod r. Both kinds of slack-cable safeties are extensively used.

63. Fig. 27 shows a worm-geared elevator built by Morse, Williams & Co., Philadelphia, Pennsylvania. In this machine the various requirements are fulfilled by slightly different means than have so far been shown, although the principles are the same. The difference lies in the manner in which the belt shifters are moved. Instead of the shipper sheave carrying the cam, the belt-shifter bars a and b have slotted cam pieces a' and b' attached to them, and the sheave carries two buttons, or projections, p and p'. It is easily seen that the effect is the same as when the shipper sheave carries the cam, with one advantage. As will be shown presently, it saves a good deal of complication in the way of gearing to put the shipper sheave loosely on the drum shaft instead of placing it on a separate stud, or shaft, in line with the shifter bars, as was done in the machines shown in Figs. 24 and 26.

As this, however, throws the center of the shipper sheave out of line with the shifter bars, the distance between must be bridged over. When using a cam on the sheave, this is done ordinarily by interposing double-arm levers l and l', as shown in Fig. 28, so that one advantage is gained at the

sacrifice of another in that case. By arranging the parts as in Fig. 27, the necessity of the double-armed levers is avoided, making the machine so much simpler. Both types are in extensive use, however.

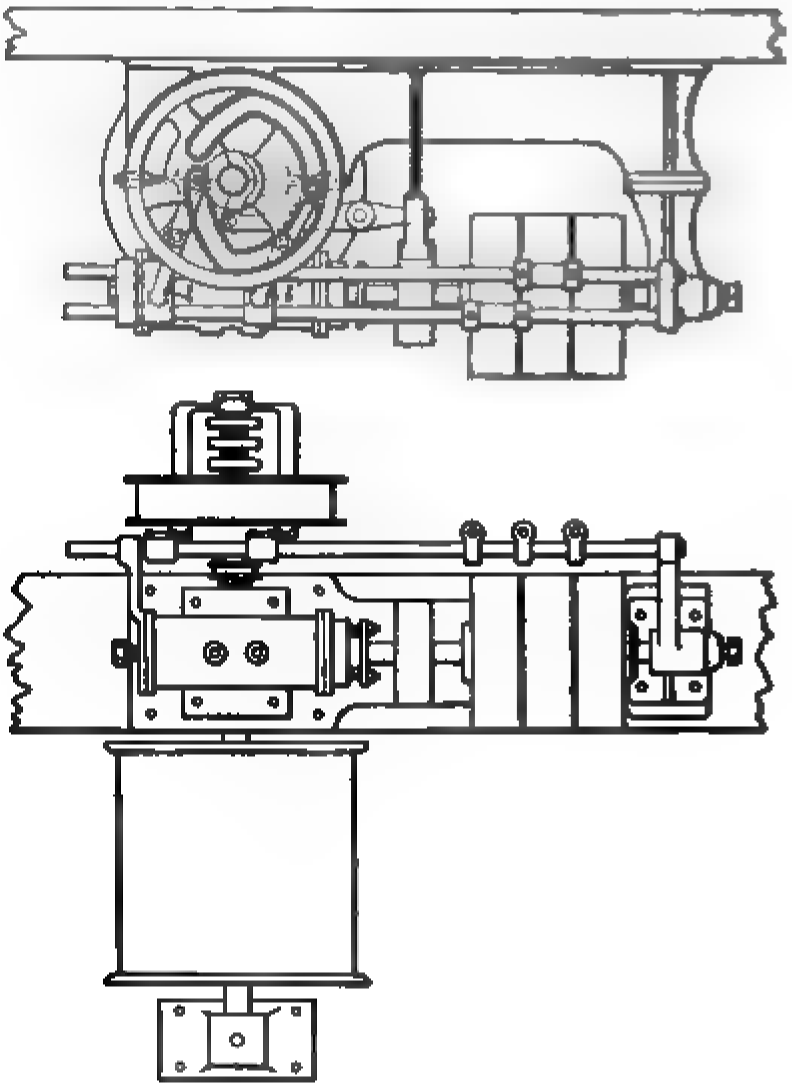


FIG. 28.

Reverting to Fig. 27, it will be seen that in turning the sheave to the right, for instance, the right-hand belt will be shifted on to the tight pulley A by virtue of the button p' entering the cam groove on the corresponding shifter-bar cam piece a'. The left-hand button p, however, will leave its cam b' entirely, and if no provision were made against it, the left-hand shifter would be unprotected, that is, liable to be shifted accidentally. To avoid this, that is, to lock the stationary shifter bar in place while the other is being moved (see requirement (c), Art. **55**), a circular groove g

is formed in the shipper sheave *S*, which fits over pins *h* and *h'* inserted in the shifter cam pieces *a'* and *b'*.

The central, or non-driving, position, as well as the extreme right and left positions, are strongly defined to the operator by the shape of the brake cam, which has a wide, flat surface for the neutral position and two smaller flat surfaces for the end positions, with the effect that when either of the corners *c* or *c'* of this cam passes through a position vertically below the center of rotation, the sheave will come to a quick and sudden stop.

64. It was mentioned in Art. **63** that by placing the shipper sheave on the drum shaft a simpler arrangement for the limit stops can be had. The usual arrangement is clearly shown in Figs. 27 and 28. The shipper sheave is provided with a yoke *y*, which takes the place of the hub. The yoke has formed on it a feather or rib *f*, upon which slides the traveling nut *n* that eventually engages with the fixed nuts *m* and *m'* in the manner already described. It is thus seen that the gearing shown in Figs. 24 and 26 is dispensed with. The yoke arrangement is in most extensive use and is found on almost every drum-elevator machine.

OPERATION AND MAINTENANCE OF BELT ELEVATORS.

65. The operation of belt elevators requires but little skill, the speed being comparatively slow; nevertheless, a certain amount of practice is required to "make the landings" exactly.

66. The operator *should never rely on the limit stops* to make a top or bottom landing, but should always operate the rope as at any intermediate floor. The limit stops are provided for an emergency and not for general use. They should be tried, however, once or twice every day, to see if they are operative and correctly set. The operator is to be cautioned against sudden reversals of the controlling device.

67. The brake needs adjusting from time to time. The necessity for this manifests itself by the car "settling" at the landings. A good deal of judgment is necessary in adjusting the brake; it should not grip too soon nor too late.

68. The belts should be kept under inspection and not allowed to become too slack. As new belts stretch considerably for a long period of time, they need closer attention than old ones.

69. Belt-elevator machines should be so installed, if possible, that the belts are not subjected to the influence of water, steam, or other moisture. In many cases, as in some factories, breweries, etc., this cannot always be done; it is then advisable to dress leather belts with a leather waterproofing compound, various brands of which are in the market, or to use rubber belts. Only first-class material should be used for elevator belts, especially if they are to be run in moist or damp places. Be careful to prevent oil from dripping on either leather or rubber belts, as the life of the same is greatly impaired thereby. Leather belting does not remain safe for any length of time in a temperature above 110° F.

70. In general, it is to be said that the elevator machine needs as much care as any other machine on the premises. It is too often considered of secondary importance and is neglected by the engineer in charge, especially as it is placed on the ceiling and more out of reach than other machinery. The bearings should be kept well oiled and the gearing should be kept clean. With regard to worm-gearing in particular, it may be well to mention that in the better class of machines it is enclosed in a casing, and the worm runs constantly in oil. This oil bath should be kept full and occasionally renewed to remove dirt and grit that may have accumulated. With new elevators this should be done more frequently than with the old ones that have been "run in"; with these fresh oil should be put in every two or three months.

71. Worm-gearing when new should, if possible, be less heavily loaded than when run in. A judicious observance of this rule is sure to prolong the life of the gearing considerably. Although conscientious manufacturers run in their worm-gearing before shipment, they can naturally do so only to a limited extent. It is said that the best oil to use on the worm bath is castor oil. The fact, however, that castor oil thickens when it becomes heated and that more or less heat is developed on worm-gearing, makes it desirable to use a mixture of 2 parts of castor oil and 1 part of the very best cylinder oil. Upon getting warm the cylinder oil runs freely, thus compensating for the property of castor oil mentioned.

72. Particular attention is to be paid to the lubrication of the thrust, or step, bearings of the worm, which should be renewed as soon as they show signs of cutting, since they will rapidly go from bad to worse. The step is generally made adjustable. The adjustment should be such that there is a little end play for the worm-shaft, say a scant thirty-second of an inch. This end play gives the oil a chance to enter between the bearing surfaces at every reversal of the worm.

If the steps are screwed up too tight, they will run hot at once and soon seize. The same as the worm and wheel, the step bearing requires to be run until a full uniform bearing surface is attained by a mutual adjustment through wear of the journal and its step. This mutual adjustment can be greatly facilitated by placing a leather washer behind the step.

73. Overhead sheave boxes must not be neglected. They should be kept lubricated with heavy grease in summer, with an addition of cylinder oil in winter.

74. Belt elevators should ordinarily not be run at a greater car speed than 60 feet per minute. The pulley speed should not exceed 400 revolutions per minute.

STEAM ELEVATORS.

CONSTRUCTION.

75. Motors.—Owing to the necessity of prompt starting, stopping, and reversing, the engines used for steam elevators are, without exception, duplex engines, generally of the vertical type. The cylinders are placed either on top or bottom, according to the kind of gearing used. Ordinary slide valves are used by some manufacturers, piston valves by others.

76. Transmitting Devices.—Practically all steam elevators are drum elevators. According to the kind of gearing used to connect the engine and drum, we can divide the elevator machines in general use into the following classes:

$$\text{Direct-geared elevators with} \begin{cases} \text{spur gearing.} \\ \text{worm-gearing.} \end{cases}$$

$$\text{Belt-geared elevators with} \begin{cases} \text{spur gearing.} \\ \text{worm-gearing.} \end{cases}$$

An example of an elevator of each class is given in Figs. 29, 31, 32, 33, and 34. The illustrations given do not by any means represent all the various designs of steam elevators, but have been chosen simply to illustrate the four types in most general use.

77. Counterbalancing.—Steam elevators are usually overbalanced when made with worm-gearing, but are not overbalanced when made with spur gears, for the same reason as belt elevators.

The engine thus furnishes full power only on the up trip of the car, and as the unbalanced portion of the car weight is generally considerable in steam elevators for the sake of safety, the engine must be of comparatively large capacity. To do away with the waste of energy in raising the unbalanced dead load of the car, and at the same time to avoid the use of the large moving masses of counterweights, recourse has been had occasionally to the expedient of connecting two cars with one hoisting drum, the ropes being so

attached to it that when one car ascends the other descends, the motor furnishing power when the load on the ascending car is equal to or greater than that on the descending one. It is evident that the pressure on the bearings of the hoisting drum is equal to the weight of both cars plus their loads, and the stress in the hoisting ropes is equal to the weight of one car with its load. By connecting the two cars by a separate rope running over overhead sheaves, the bearings of the drum and the hoisting ropes are relieved of the car weights.

The obvious advantages of this double-car method of counterbalancing are, of course, gained at the disadvantage that both cars must move simultaneously.

78. Controlling Devices.—The controlling devices of a steam elevator consist of a steam-reversing valve and brake operated by a shipper rope, which is either a simple shipper rope or is in connection with some lever or wheel-operating device.

79. The steam valves used in the machine represented in Fig. 29, which is an **Otis spur-geared steam elevator,** are piston slide valves operated, as in most slide-valve engines, by eccentrics on the main shaft.

80. The reversing valve, which is shown in three positions in Fig. 30, reverses the motion of the engine by changing the piston valve of each engine from a direct to an indirect valve, and vice versa. Referring to Fig. 30 (*a*), the reversing valve *a* is shown in the position it occupies when hoisting. The valve is surrounded by live steam, which is also admitted to the cavity *b*. The live steam now flows through the ports *c*, *c'* into the passages *e* and *e'* leading to the ends of the piston valve, which now operates as a direct valve, taking steam at the ends and exhausting at the center. The exhaust from the piston valve passes through the passage *d* and ports *o*, *o'* into the exhaust passage *f*.

81. For lowering, the reversing valve occupies the position shown in Fig. 30 (*b*). Live steam now passes through

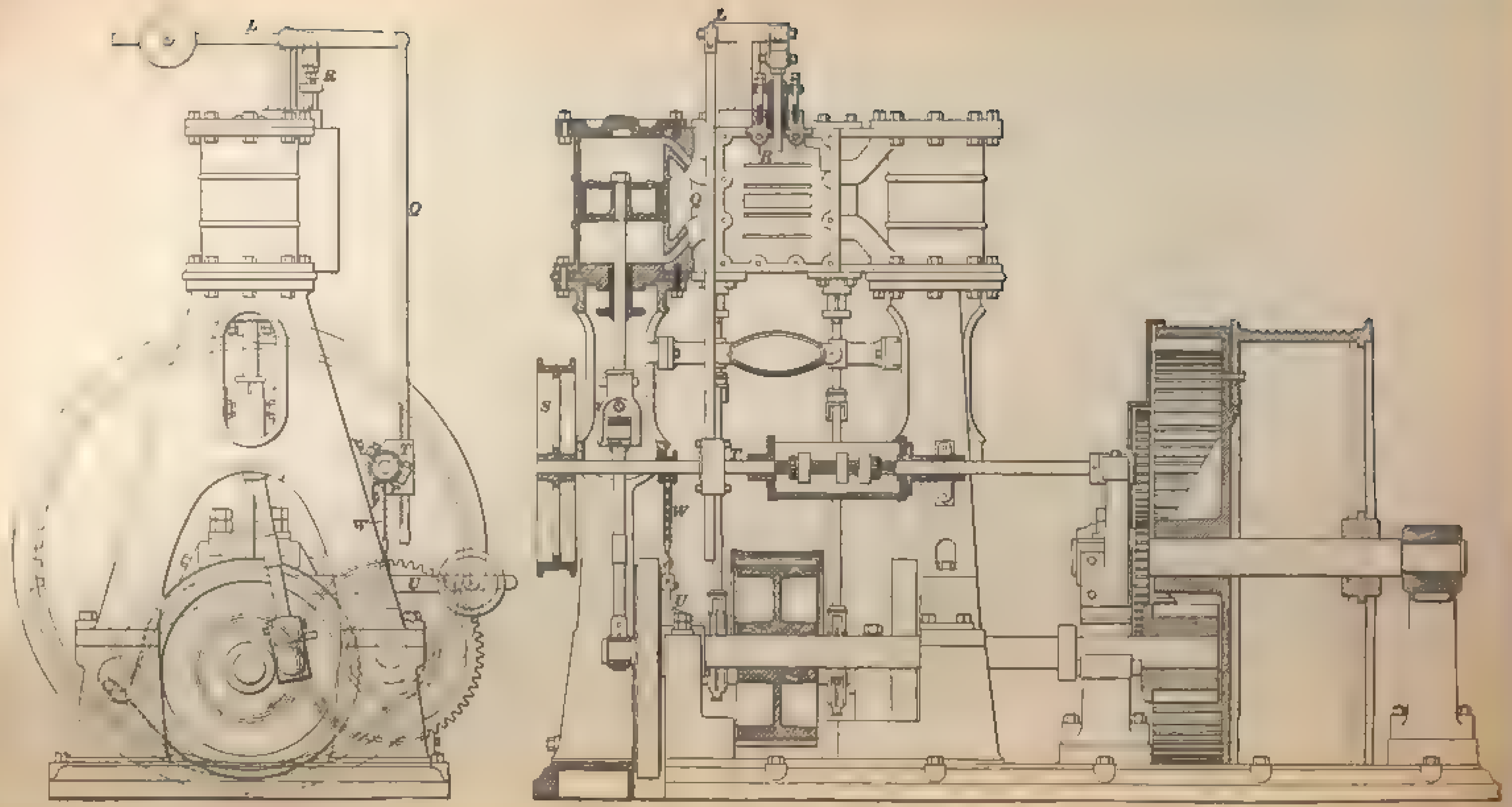


FIG 29

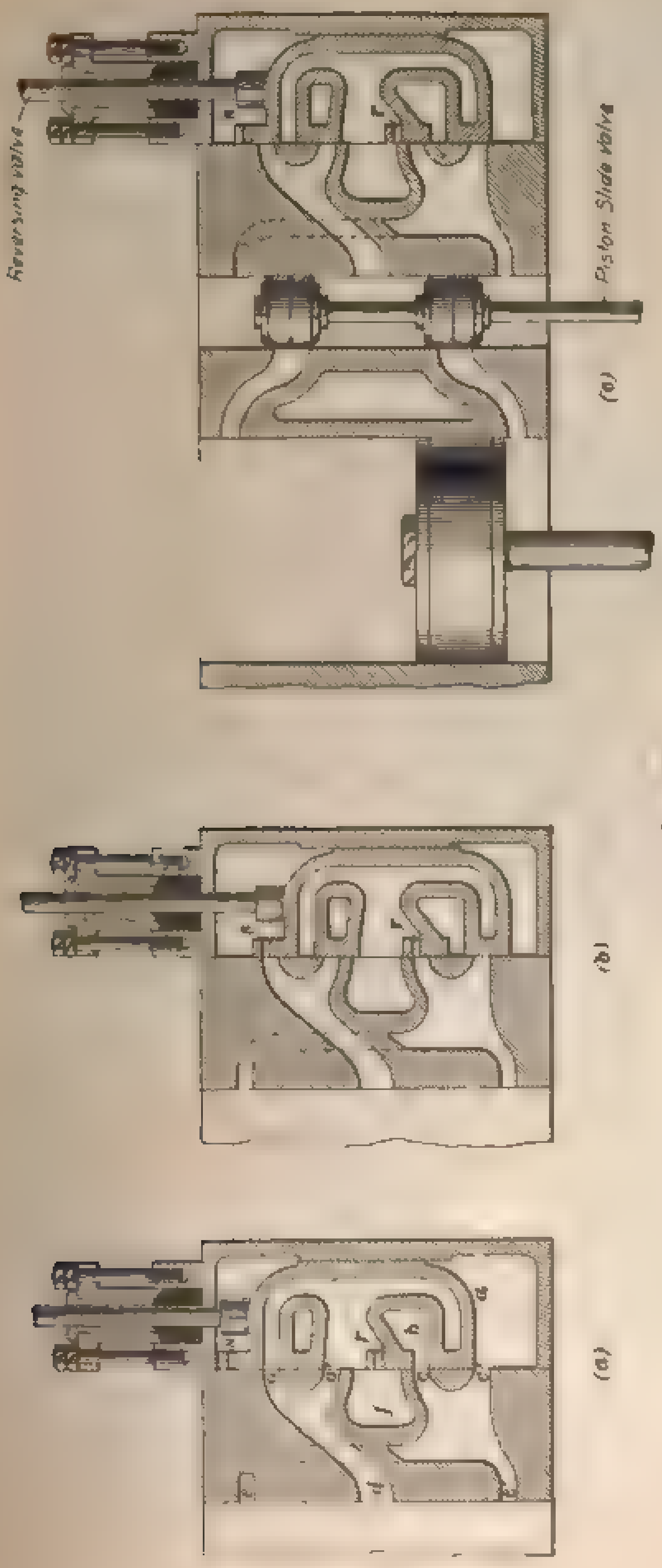
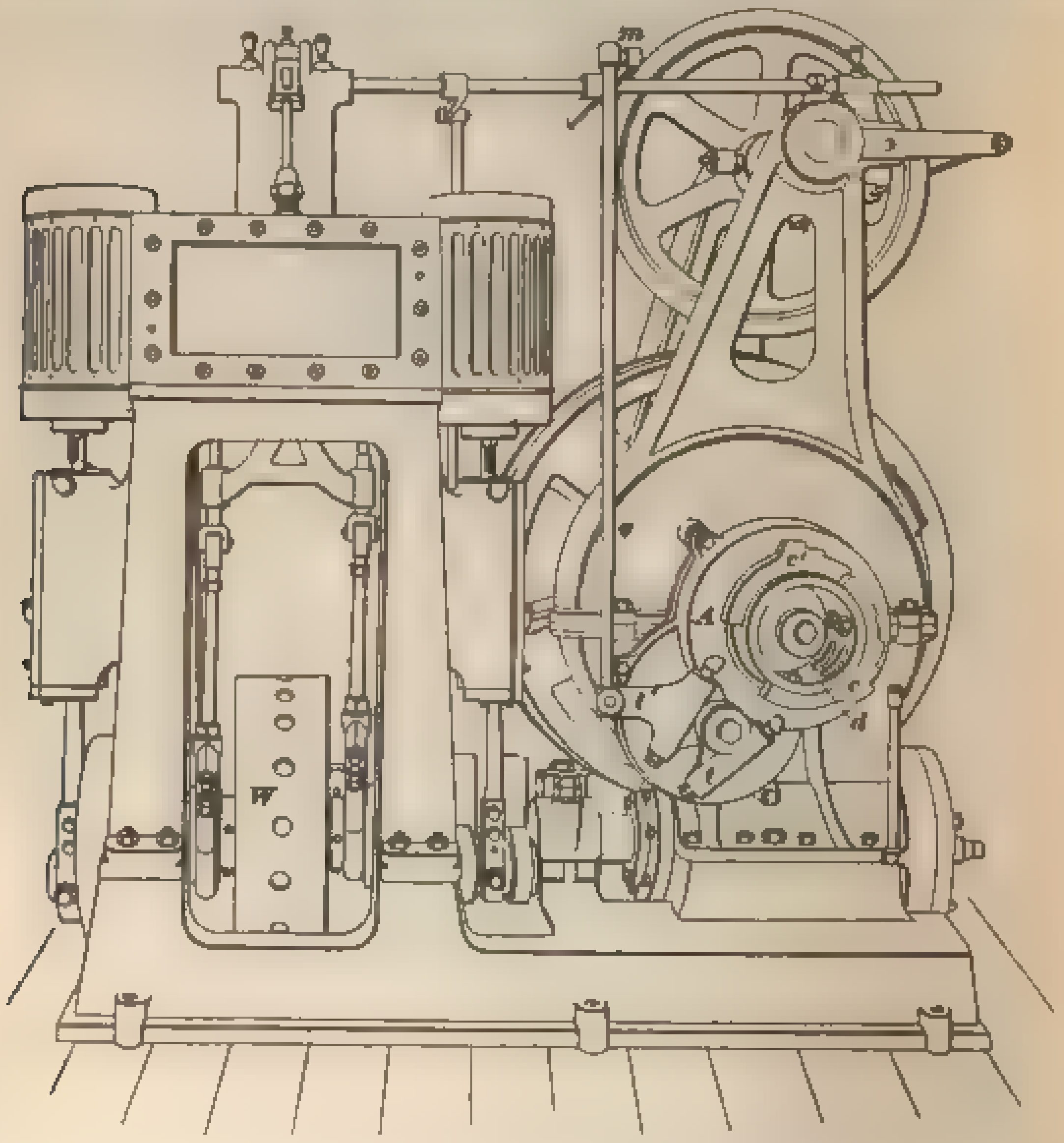


FIG. [illegible]

the small port *s* into the port *o* and thence through the passage *d* to the center of the piston valve, converting it into an indirect valve and thus reversing the motion of the engine. The exhaust from the engine passes through *c* and *e* into the port *c*, and thence through the small port *r* in the valve to the exhaust passage *f*. The elevator being under-



(a)

FIG. 31 (a).

balanced, the car descends by gravity, so that the steam ports need be uncovered entirely only for hoisting. Only enough steam to overcome the friction of the engine is needed in lowering, and for this reason the port *s* that admits steam for lowering is very small, being made up of a series of small holes drilled through the valve. The port *r* is constructed in the same manner.

82. When the car is at rest, the reversing valve occupies the position shown in Fig. 30 (*c*), where all ports are covered. A motion of the reversing valve in an upward direction will start the engine and hoist the car; a downward motion of the reversing valve will let the car descend.

83. The stem *R* of the reversing valve (see Fig. 29) is attached to a lever *L* that is actuated by a rack *Q* and

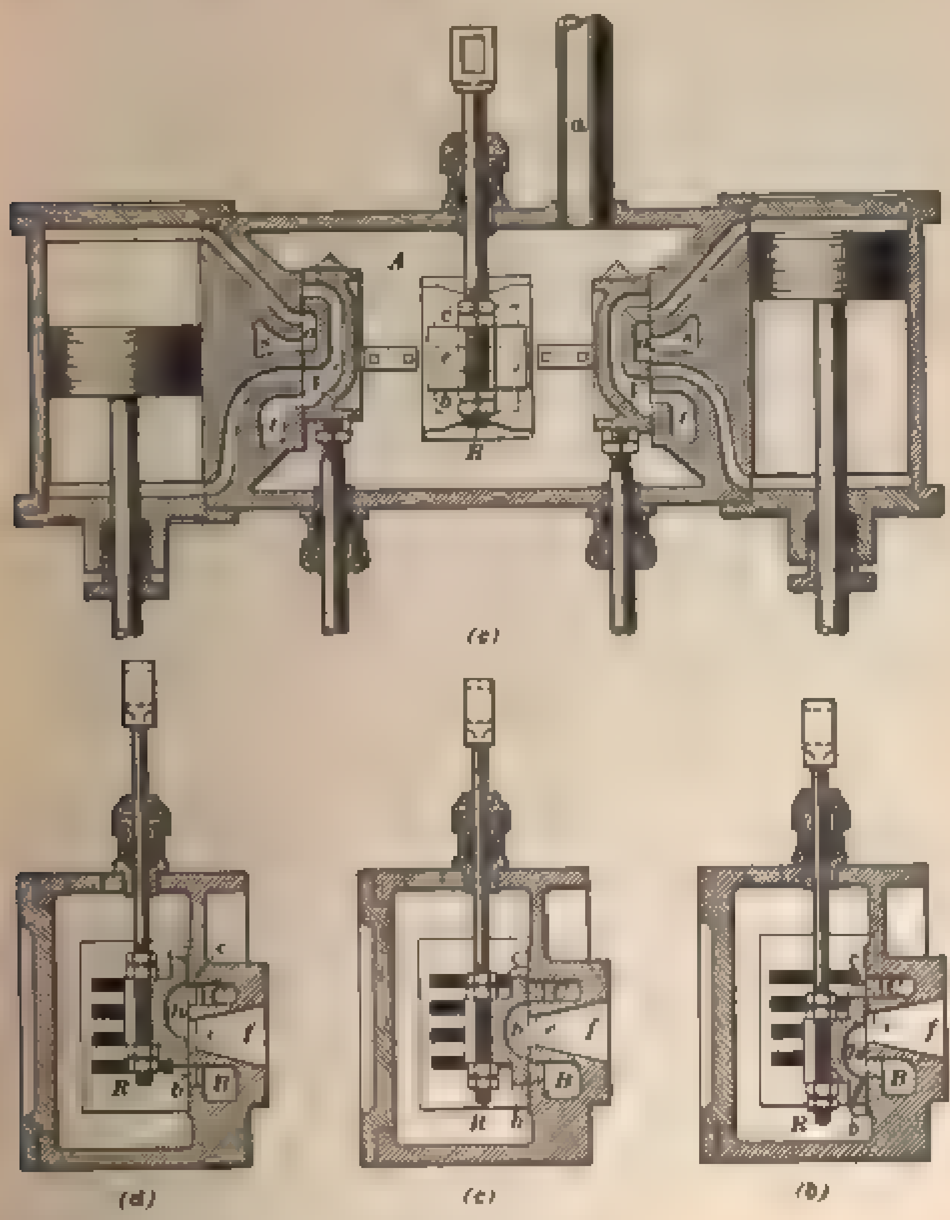


FIG. 31 (*b*), (*c*), (*d*), (*e*)

pinion *P* from the shipper-sheave shaft *T*, which latter is also connected to the brake lever *U* by a chain *W*. The operation of the brake is plain from the drawing.

84. The reversing valve in the machine shown in Fig. 31 (*a*), which is a **Crane worm-geared steam elevator,** is somewhat different from the Otis valve just described. Its action will be understood from Fig. 31 (*b*), (*c*), (*d*), and (*e*). Fig. 31 (*e*) is a vertical section through the two engine cylinders and the valve chest showing the steam-distributing slide valves *V*, *V'* in section and a front view of the reversing valve *R*, while Fig. 31 (*b*), (*c*), and (*d*) are transverse sections showing the three positions of the reversing valve. The action is as follows. Steam enters through the pipe *a*, Fig. 31 (*e*), the steam chest *A*. If the reversing valve *R* is moved to the position shown in Fig. 31 (*b*), the port *c* is opened, thus allowing steam to flow through the passage *C* into the cylinders, while the exhaust passes through passage *B*, port *b*, cavity *h* of the reversing valve, exhaust port *e*, and duct *f* into the atmosphere. To stop, the reversing valve is moved to the position shown in Fig. 31 (*c*), when it closes the passages *B* and *C*. To reverse the machine, the reversing valve is moved to the position shown in Fig. 31 (*d*). Steam then enters *A* through *a*, as before, but goes through port *b* and passage *B* to the distributing valves *V*, *V'*, while the exhaust passes through passage *C* and port *c*.

85. The manner in which the engine is reversed may be explained as follows: The port *c* and passage *C* connect with the steam passage *s*, and the port *b* and passage *B* connect with the steam passage *t* in the valve seat of each engine. With the reversing valve in the position shown in Fig. 31 (*b*), the live steam is admitted through *s* into the central cavity *o* of the steam valves, while exhaust takes place through *t*. It is thus seen that the valves are now indirect. When the reversing valve takes the position shown in Fig. 31 (*d*), the live steam passes through *b* and *B* and through *t* into the steam valves, while now the exhaust steam passes through *s* into the cavity *h* of the reversing valve, and thence into *e* and *f*, and finally into the atmosphere. In this position the steam valves act as direct valves and give a motion

to the engines contrary to that obtained when the valves act as indirect valves.

86. There is no brake shown on this machine. The worm having a sufficiently low pitch to make it self-locking, a brake is often dispensed with. When used, however, it consists of a wooden brake shoe, which is pressed against the wheel by means of springs and released by live steam.

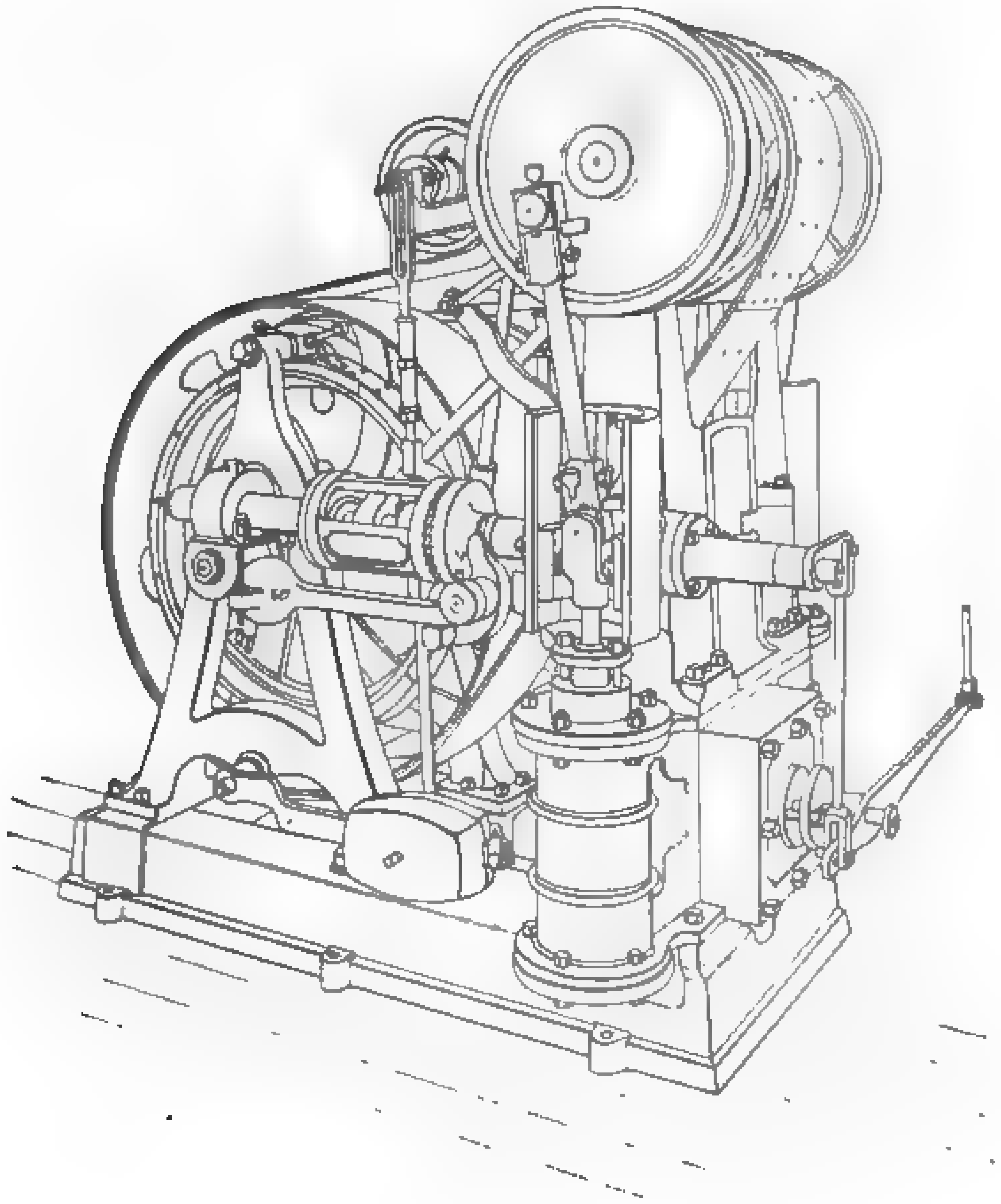


FIG. 32.

87. In the machine shown in Fig. 32, which is a belt and spur-gear steam elevator built by the Otis Elevator Company,

a rotary reversing valve is used. Its action is much the same as that of the Otis reversing slide valve previously described.

88. Fig. 33 is an illustration of a belt and spur-gear steam elevator. The machine is built by the Otis Elevator Company of Chicago, formerly the Crane Elevator Company. The same kind of reversing valve is used in it as in

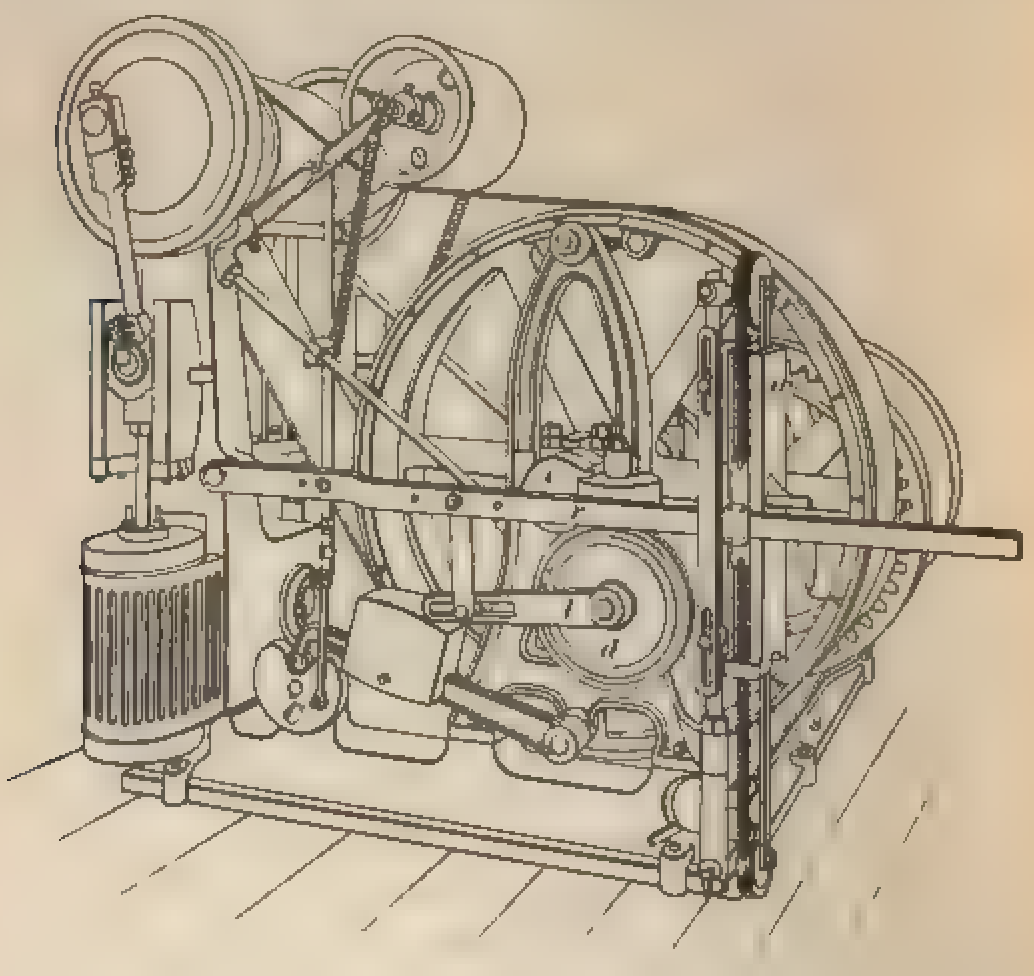


FIG. 33.

the machine shown in Fig. 31. Among the controlling devices in this machine is to be noted the heart-shaped brake cam C, the deep notch of which marks the central, or non-driving, position of the controlling mechanism.

89. Fig. 34 is an example of a belt and worm-geared elevator built by The Whittier Machine Company, now consolidated with the Otis Elevator Company.

90. Motor Safeties.—Motor safeties are provided in all cases, either in the shape of limit stops of the ordinary yoke

type, as shown in Figs. 29 and 32, or of special design with the same underlying principle as shown in Fig. 31 (*a*).

91. The device used in the machine shown in Fig. 31 has some additional features, and is, therefore, shown in detail in Fig. 35.

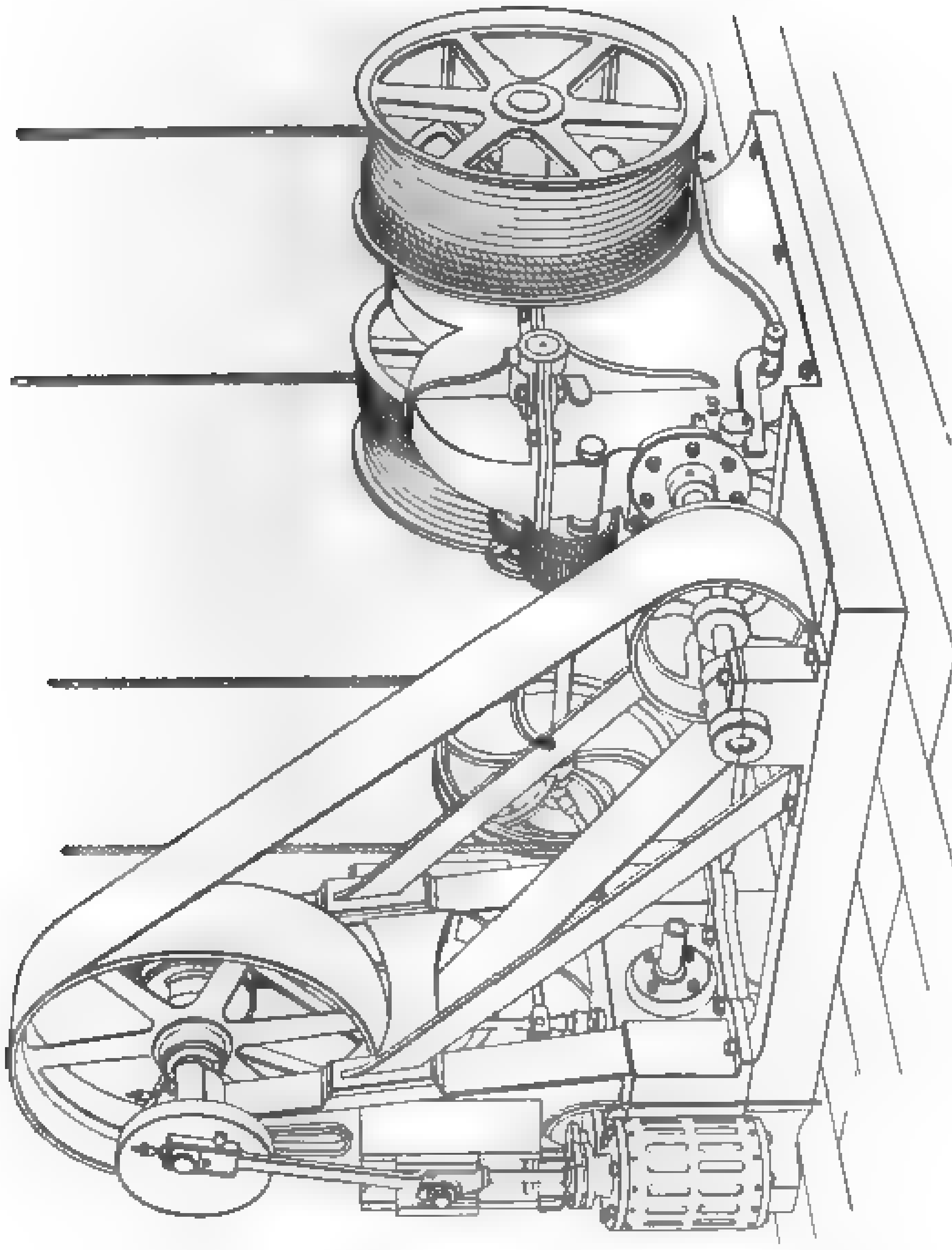


FIG. 34.

The winding-drum shaft carries a pinion p, Fig. 35 (*a*), meshing with a gear g. This latter gear has a second pinion p', which is solid with it and meshes with another gear g' mounted loosely on the winding-drum shaft. This gearing, which is similar to the back gearing of a lathe, is such that

the gear g' will make less than one revolution for the whole number of revolutions of the drum shaft necessary to lift the car to the top. To the gear g' is attached a drum having long slots [see Fig. 31 (*a*)] into which are fitted adjustably the cams c, c', shown in Fig. 31 (*a*) and Fig. 35 (*b*), (*c*), and (*d*). These cams are located on the

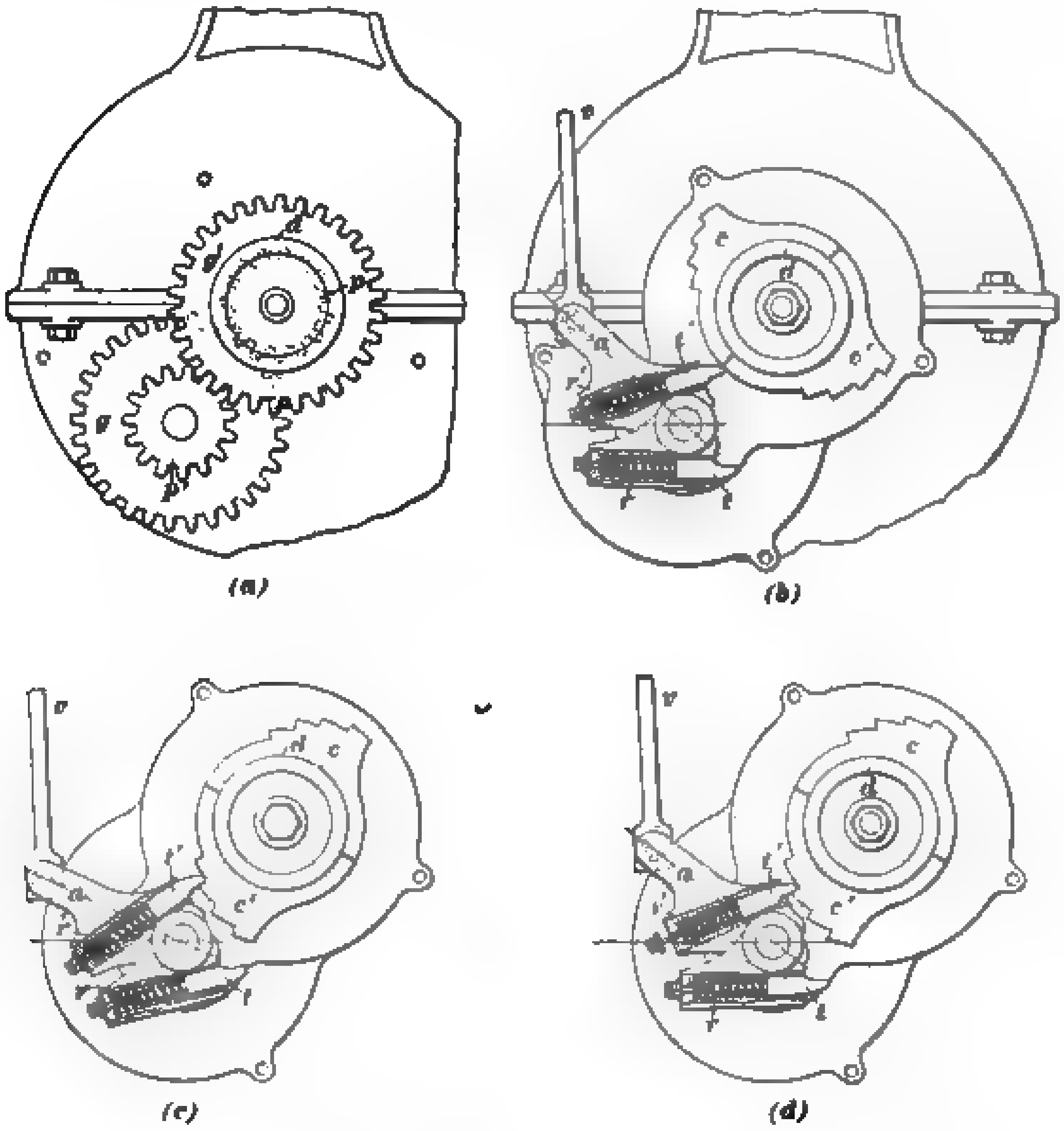


FIG. 35.

drum d in different planes and have two or more steps, as shown, and engage eventually each one of two spring-actuated triggers t, t' mounted in rockers r, r' on a stud and in planes corresponding to those of the cams. One of the rockers, which are rigidly connected to form one piece, has an arm a, to which is connected the rod v leading to the

valve lever *m*, as shown in Fig. 31 (*a*). When the car reaches the top or bottom, respectively, of the hoistway, either cam *c* or *c'*, as the case may be, engages its particular trigger *t* or *t'* and pulls or pushes the valve rod *v*.

Fig. 35 (*b*) shows the position of the various parts when the car is about midway in the elevator shaft. Suppose now the car to go up; then, as it nears the limit of its upward travel, the cam *c'* will engage the trigger *t'* with the first one of the steps and thus move the valve rod *v* until the trigger passes over the first step, as shown in Fig. 35 (*c*). This will slow down the car; on a farther motion of the car the second step of the cam will come into contact with the trigger, pulling the valve rod still farther, thus slowing down the car still more, and so forth, until the steam valve is entirely closed and the car stops.

92. The gradual choking off of the steam supply by the successive steps has the effect that with a heavy load on the car the latter will finally reach the top very much slower than with a light load, and may even stop short of the last landing. Conversely, if the apparatus is so adjusted that with a heavy load the car will finally stop at the lowest landing, it may do so with a light load, but only very slowly and even may not reach the landing. The apparatus illustrated in Figs. 31 and 35 provides for these conditions, inasmuch as it permits the operator on the car to operate the controlling device to some extent even after the automatic stop has performed its function. This is accomplished by making the triggers *t*, *t'* spring actuated. The springs will not yield to the action of the cams, the pressure being a transverse one, but they will yield if a pull or push, respectively, is exerted on the valve rod *v* by the operator. Thus, if it is found, for instance, that after the cam *c'* [see Fig. 35 (*c*)] has acted upon the trigger *t'* so as to slow down the car, the latter moves too slowly, the operator may pull on the rod *v* and bring it into position shown in Fig. 35 (*d*), the spring of said trigger permitting this, and thus partly reopen the steam port.

93. The machine shown in Fig. 33 has a different arrangement for an automatic stop. Back of the disk *d* is a plate revolved from the drum shaft by a worm and gear (covered in the illustration by the case *c*). This plate has a spiral groove that moves a stud connected to the disk *d* in and out until it strikes and touches on adjustable stops and causes the disk *d* and lever *l* to turn with it, thus centering the reversing lever *r*.

94. Slack-Cable Safety.—Slack-cable safeties are generally provided on all steam elevators, although shown only in Figs. 32, 33, and 34. They consist in all cases of a rod running across the under side of the winding drum and so arranged that it is depressed by the weight of any loose cable that may form. When so depressed, it releases a spring or weight, which, in turn, acts upon the controlling device, shutting off the steam. The aforesaid rod is seen in Figs. 33 and 34 at *s* and the weight at *w*. In Fig. 32, the weight *w*, when released, throws in a clutch that causes the limit-stop yoke to turn the valve rock shaft.

OPERATION AND MAINTENANCE.

95. The operation of a steam elevator is exceedingly simple and at once familiar to every one able to run a steam engine. Too great care cannot be bestowed on the hoisting ropes and the various safety appliances; the weights handled by steam elevators being usually great, the risk to human life that is incurred by neglect on the part of the engineer is correspondingly great.

96. In belt geared elevators, attention must be paid particularly to the driving belt. A breakage of this belt, it will be observed, throws the car and all there is upon it on the car safeties with disastrous results if the latter should prove inefficient. An elevator belt performs a duty much more severe than ordinary belting; it runs over a large and a small pulley and under an idler to give it as great as possible an arc of contact on the small pulley; it must also run in

opposite directions alternately, so that there is always considerable slip. Such a belt should, therefore, be of the best quality obtainable and should be well cared for. The leather used should be genuine oak-tanned stock; the pieces should be cut from the hide in such a way that the hide center will be the center of the belt. The pieces should be well stretched before being made up. They should not be more than 50 inches in length, including laps, and should be joined by a so-called *lock lap*, making a perfect joint. A *straight lap should not be used under any circumstances.* Besides being of best quality, the cement used must be very pliable on account of the short turn of the belt under the idler and over the small pulley. The belt should be riveted as a precaution against a lap becoming loose, so that the rivets may hold the defective lap together until it is discovered and repaired.

Lacing belts must not be resorted to, as the laces soon break, due to running over the small pulley.

It is recommended by elevator men to give the belt an occasional dressing with castor oil to keep it pliable.

ELEVATORS.

(PART 2.)

ELECTRIC ELEVATORS.

INTRODUCTION.

1. Treating elevators in the order of their development, the hydraulic elevator would follow after the steam elevator, because the electric elevator is the latest competitor in the field. Nevertheless, as most electric elevators are of the drum type, and therefore similar in many ways to hand, belt, and steam elevators, they will be considered before the older type.

INDIRECT-CONNECTED ELECTRIC ELEVATORS.

BELT-CONNECTED, BELT-SHIFTING ELEVATORS.

2. The first mode of application of the electric motor to elevator machinery was simply a substitution of an electric motor for whatever kind of power was previously used for driving the line shafting of an ordinary belt elevator. The motor was started by an ordinary main switch and starting box and ran continuously in one direction, the elevator being controlled in the same manner as other belt elevators. If such an elevator is not in constant use, the electric motor must be stopped and started frequently, which, with an

ordinary switch and hand starting box, compels the operator to go to the starting box every time the elevator is used. To avoid this, the switch and starting box are operated by a hand rope running through the car in the same manner as the shipper rope, or to avoid the handling of the two ropes, the shipper rope may serve both for shifting the belts and for cperating the switch and rheostat.

BELT-CONNECTED, BELT-SHIFTING, REVERSIBLE-MOTOR ELECTRIC ELEVATOR.

3. General Description.—By introducing a reversing switch instead of the single switch, the motor can be reversed by reversing the current in the armature. The necessity for two belts, an open and a crossed one, is then obviated, and one belt between the countershaft and elevator machine is sufficient, this belt being shifted from a loose pulley to a tight one to start the car in either direction, that is, up or down.

4. Belt-shifting electric elevators being nothing but combinations of belt elevators with an electric motor, we can confine our remarks with respect to the various parts of these elevators to motors and controlling devices, all the other parts being the same as in ordinary belt elevators.

5. Motors.—For belt-shifting elevators, continuous-current, constant-potential, shunt-wound, single-speed motors are generally used, and since the motor starts without load, no rush of current that might injure the armature takes place at starting. Any kind of alternating-current motor may be used for belt-shifting elevators when the motor runs continuously. When, however, the motor is to be stopped and started frequently, polyphase synchronous motors or induction motors must be used, because these motors will start by themselves, while single-phase motors will not.

6. Controlling Devices.—Aside from the belt shifters for belt-shifting elevators, the power control consists of a switch and a rheostat. For combinations in which the

motor runs continuously in one direction and is started and stopped only occasionally, the ordinary switch and starting box operated by hand are sufficient. If, however, the switch and rheostat are to be operated by a hand rope or other operating device from the car, special mechanisms become necessary, since the simple pull on the hand rope cannot give the necessary motions. To prevent a possible damaging rush of current in starting such an electric motor as is used in elevator work, the main switch is closed with all the starting resistance in the armature circuit, which resistance is then gradually cut out as the speed of the motor increases, until the motor is finally (when running at its normal speed) connected directly to the mains. After stopping, this resistance should all be in again, so as to make the apparatus ready for the next start; and since starting may follow quickly upon stopping, this restitution of the apparatus to its starting conditions after stopping must be effected quickly. When the switch and starting box are manipulated by hand, the above requirements can be easily fulfilled, but not when they are operated together from a hand rope. To obtain the required motions, various contrivances have been devised and are largely used. A few examples are given.

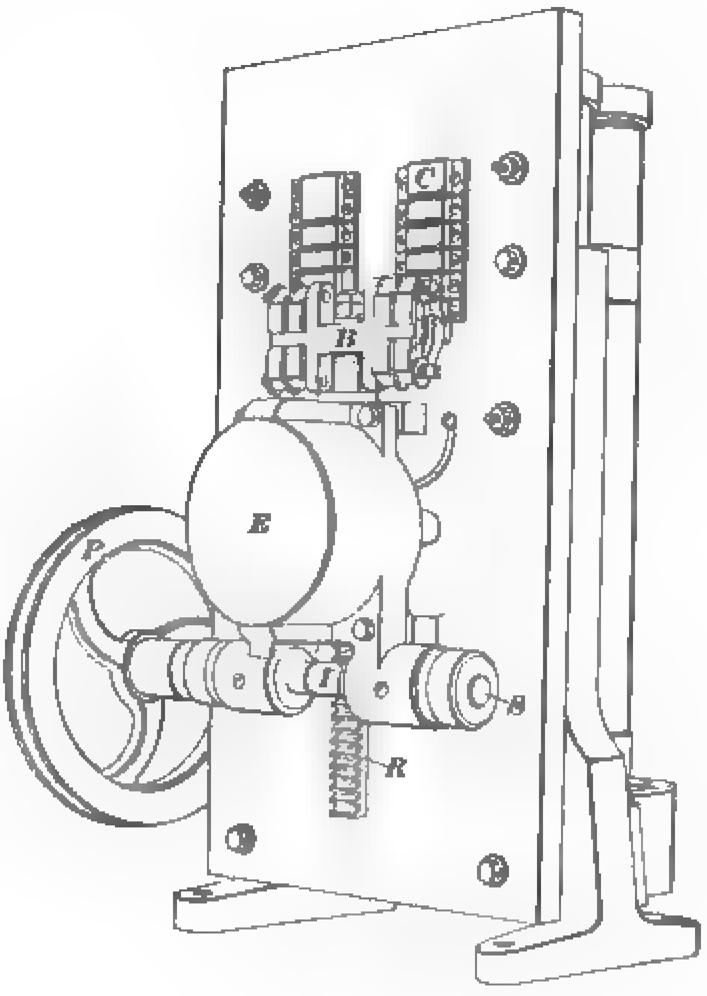


FIG. 1.

7. Mechanically Operated Rheostats. — The most natural way to

gradually cut out the starting resistance as the speed of the motor increases is to mechanically connect the starting box to the motor shaft. Fig. 1 shows an apparatus made by the Automatic Switch Company and designed to be used with motors running always in one direction, that is, in our case, with an indirect-connected or belt-shifting, non-reversible elevator machine. The pulley *P* is belted to a smaller pulley on the motor shaft or countershaft and drives a shaft *S* having formed on it a two-toothed pinion *I*. When the motor is running, a rack *R* is drawn into mesh with the pinion *I* by means of an electromagnet *E* energized by a coil in shunt with the motor circuit. As soon as the circuit is closed and the motor commences to revolve, the rack ascends and with it the contact bar *B* that is carried on its upper end. The contact bar passes successively over the contacts *C*, gradually cutting out resistance. As soon as the current is broken, the magnet is deenergized and the contact arm drops back, the rack *R* springing out of gear with the pinion.

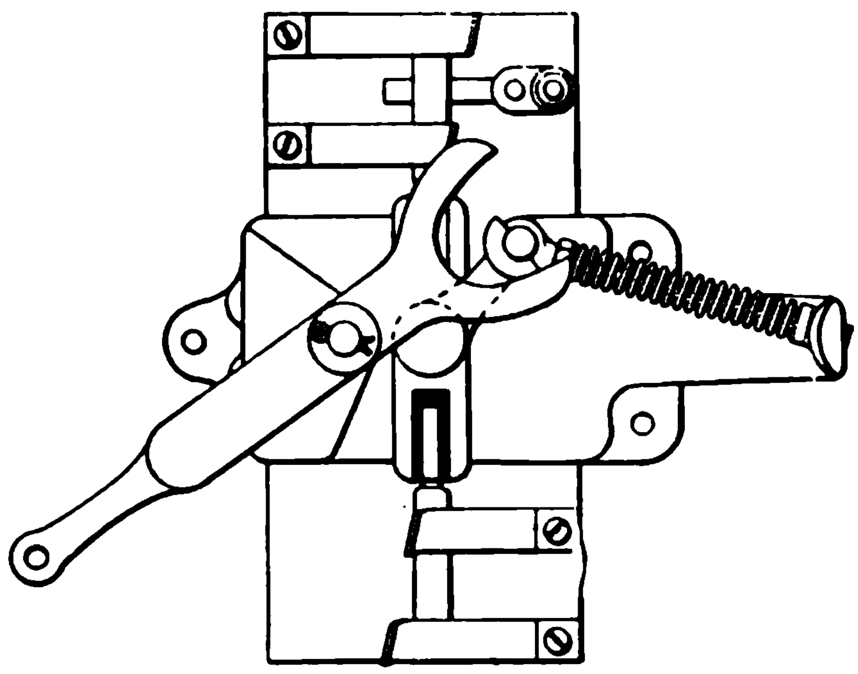


FIG. 2.

8. In connection with the starter shown in Fig. 1, a simple snap switch is used, such as is shown in Fig. 2; the action of this will be readily understood. It is operated either by hand or by a separate hand rope or cord running parallel to the shipper rope in the hoistway.

9. Fig. 3 is a diagram of an installation using the starting box shown in Fig. 1. Fig. 4 is a diagram of the connections; this will prove useful to engineers wishing to drive existing belt elevators by an electric motor.

10. In case a belt-shifting elevator is to be run with a single belt, the motor must be reversible. A **reversing**

switch is then used instead of the single snap switch shown in Fig. 2. Such a reversing switch, made by the Automatic Switch Company, is shown in Fig. 5, which also gives a diagram of the connections. The reversing switch has

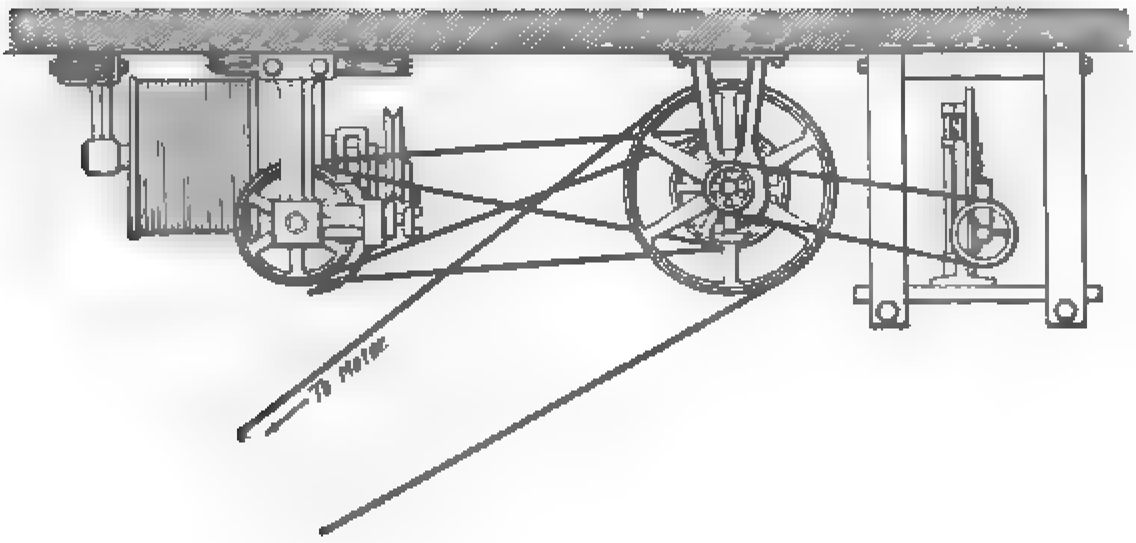


FIG. 3.

four sets of contacts a, b, a', b', each consisting of three clips, and two blades B and B', which are insulated from each other. The clips are connected with the terminals of the various parts (motor armature, field, resistance,

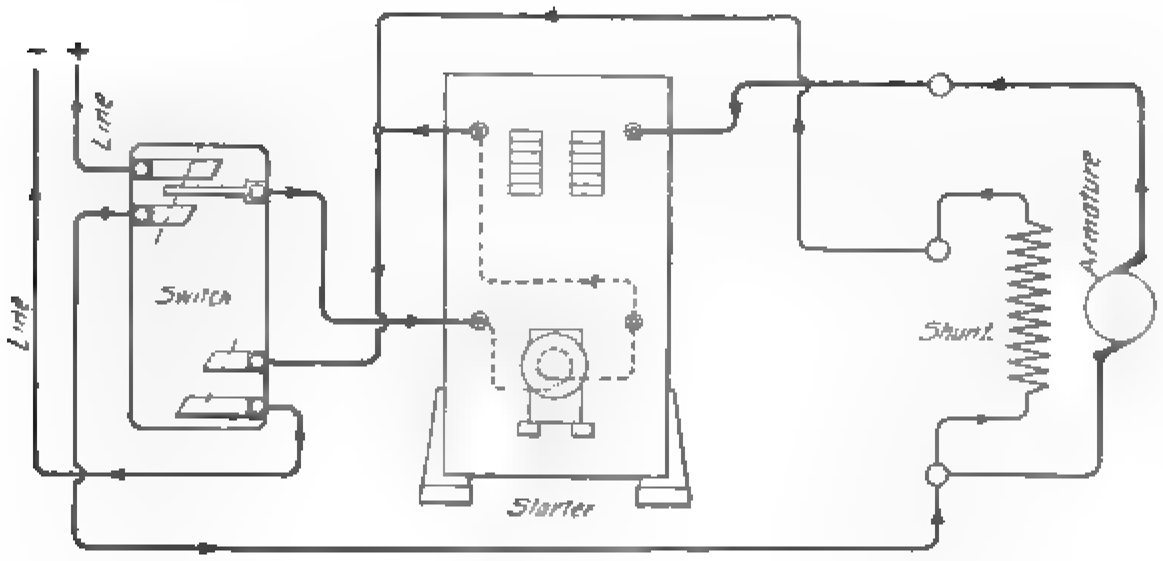


FIG. 4.

and starter magnet), as shown. When the switch is pulled up, blade B connects the three clips at a and blade B' connects the three clips at b. This allows the current to flow through the armature, the shunt field, and the

resistance, and the elevator ascends. When the reversing switch is pulled down, *B* connects the three clips at *a'* together and *B'* connects the three clips at *b'*. This reverses the flow of the current through the armature, because the wires on the switch that connect the upper and lower horizontal clips are crossed; the current in the shunt field flows in the same direction, no matter whether the switch is up or down; hence, pulling down the switch

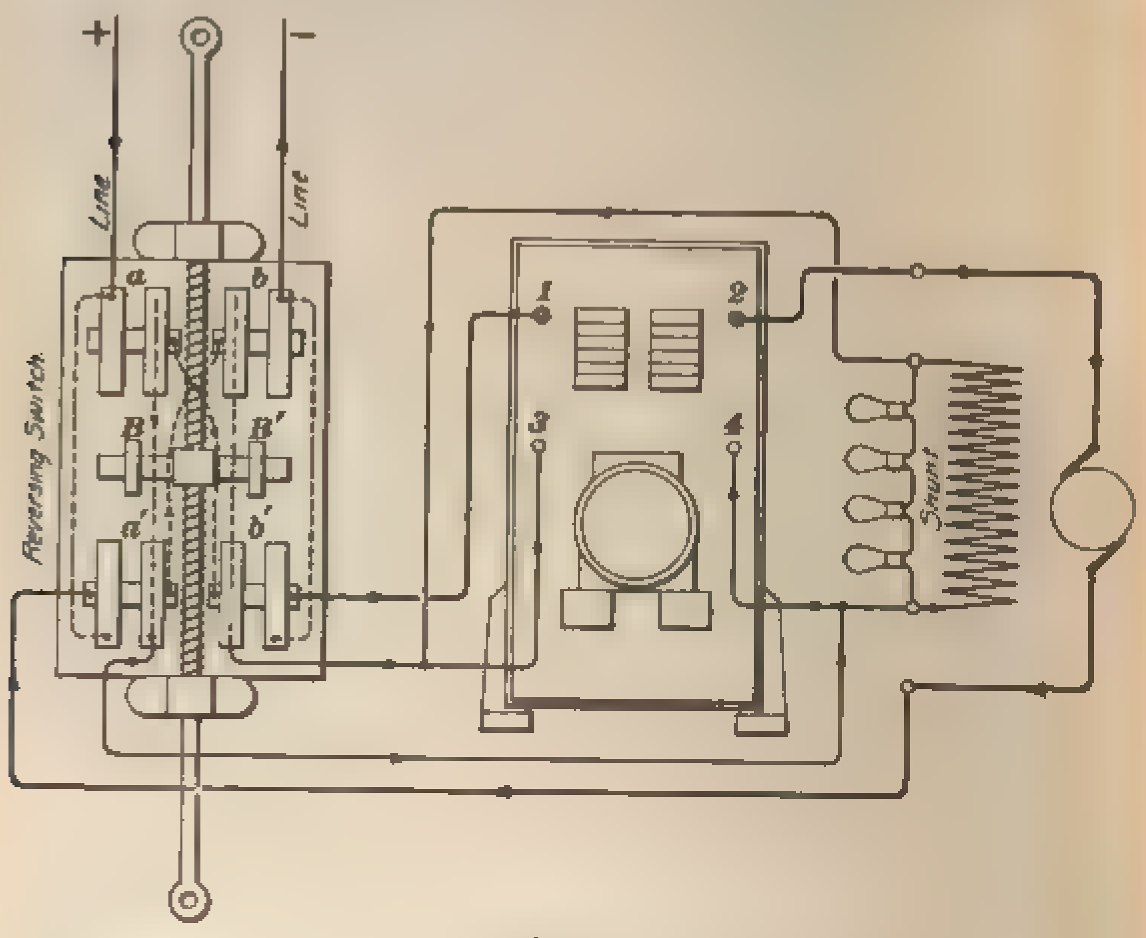


FIG. 5

reverses the motor. The terminals of the armature resistance are shown at *1* and *2*; *3* and *4* are the terminals of the magnet that throws the rack into and out of gear. With this explanation the student will be able to trace the path of the current without difficulty.

11. It is often observed on opening the circuit that there is considerable sparking at the clips connected to the shunt field. This is due to the self-induction of the field. To reduce this sparking, it is a good plan to connect across

the shunt a series of incandescent lamps having a combined voltage of from 6 to 8 times that of the line current; that is, in case a 110-volt lighting current is used, a series of, say, four 220-volt lamps is inserted, through which the induction current of the field is discharged. Since the starter is belted to the machine or countershaft, it will be reversed with it; it must, therefore, be so arranged that it will lift the cross-bar *B*, Fig. 1, no matter in which direction the motor runs. This is done in this kind of starter by substituting for the two-toothed pinion *I* an eccentric operating a pawl. Otherwise the "reversible starter" is the same as the "non-reversible" one.

12. Another kind of mechanically operated starter is shown in plan and elevation in Fig. 6. It is made and patented by the Otis Elevator Company. Its action is different from the apparatus described in the foregoing article in so far that it is not connected mechanically to the motor or countershaft but to the main-switch spindle, and the gradual cutting out of resistance is obtained by a dashpot. The following description is taken from the patent specifications:

A box *A* contains in its rear part *A'* resistance coils, and in its front part the operating mechanism, the essential features of which consist of a snap switch *1*, an arm *2* for operating the snap switch, and a brush-carrying arm *3*, which brush operates in connection with a resistance device *10*; the brush arm *3* is, in the present instance, provided with a counterbalance *9* and controlled by a dashpot *4*; arm *3* is mounted on a shaft *5*, by means of which it is operated in the manner described later.

The switch *1* comprises essentially a knife blade *7*, mounted on a pivot *6*, adapted to engage and disengage the contacts *8*, *8*, and connected to this knife is a cam *16* having a notch *17*, into which projects the end of the arm *2* for moving the cam; the cam is further provided with recesses and projections *18*, with which a spring catch *15* coöperates, under the stress of a spring *15'* for holding the switch

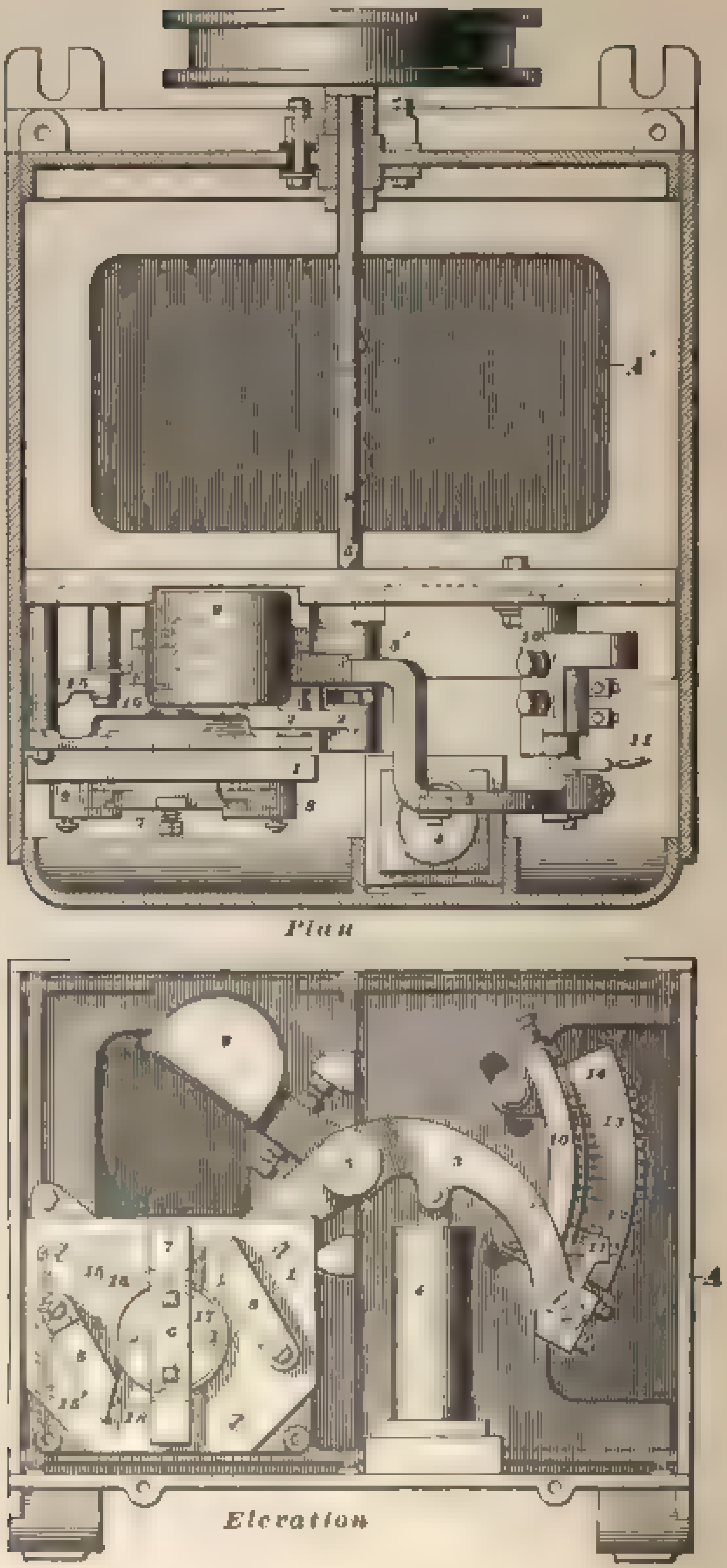


FIG. 6.

in different positions and for making it complete its movements after it has been started, so as to produce the sudden engagement and disengagement in the manner well known in connection with snap switches. The arm *2* is rigidly connected to the shaft *5* so as to move therewith, while the brush-carrying arm *3* is loosely mounted on the shaft *5*; interposed between the two arms is a catch, or stop, so arranged that the arm *2* may move independently of the arm *3* when the parts are in one position, but when it is moved in the opposite direction and the arm *3* is in another position, they will move together. This catch consists of a projection *2'* on the hub of the arm *2* working in a slot *3'* in the hub of the brush-carrying arm *3*.

The brush-carrying arm *3* carries a brush *11* adapted to bear on the resistance-contact device *10*, and the contacts are arranged so that the contact *12* will permit a considerable movement of the brush before any of the resistance is cut out. While the contacts *13* are connected by the resistances in box compartment *A'* in the usual way, the contact *14* is connected directly with the line; so that while the brush is on the contact *12* all the resistance is included in the circuit, and as it sweeps over contacts *13* more or less of the resistance is cut out until it bears on the contact *14*, when all the resistance is out of the circuit. This resistance device *10* is made on the arc of the circle and is adjusted in the box by means of lugs and bolts engaging slots in the frame of the box.

In the figure, the circuit is shown open and all the resistance is included in the circuit, the catch *2'* bearing on one side of the slot *3'* of the brush-carrying arm *3*, holding the parts in the position shown. If, now, the shaft *5* is turned in the direction of the arrow, that is, to start the motor, the arm *2* operating through the cam *16* will move the switch blade 7 so as to engage the contacts *8*, the spring catch *15* riding over the projection *18* and tending to complete the throw of the switch arm as it enters the adjacent depression on the other side of the projection *18*, making a snap switch. The catch *2'* moves through the slot *3'* and leaves the

brush carrying arm 3 free to move, which, under the influence of the counterbalance 9, it commences to do at once, but its movement is retarded more or less by the dashpot 4. The parts are so arranged that before the brush 11 moves off the resistance contact 12, the switch 1 has closed the circuit through the contacts 8 and the brush-carrying arm moves gradually over the resistance contacts, cutting them out, until the brush 11 bears on the contact 14, by which time the motor has come up to speed. When the shaft 5 is turned in the direction opposite the arrow, that is, to stop the motor, the projection 2 bears on the side of the slot 3' so that as the arm 2 is turned to open the switch 1, the brush 11 is moved over the resistance contacts, insuring the inclusion of the resistance in the circuit. It will be noted that the slot 17 in the cam 16 is of such dimensions as to permit the inclusion of a greater part of the resistance contacts before the knife blade 7 is actually moved from the contacts 8.

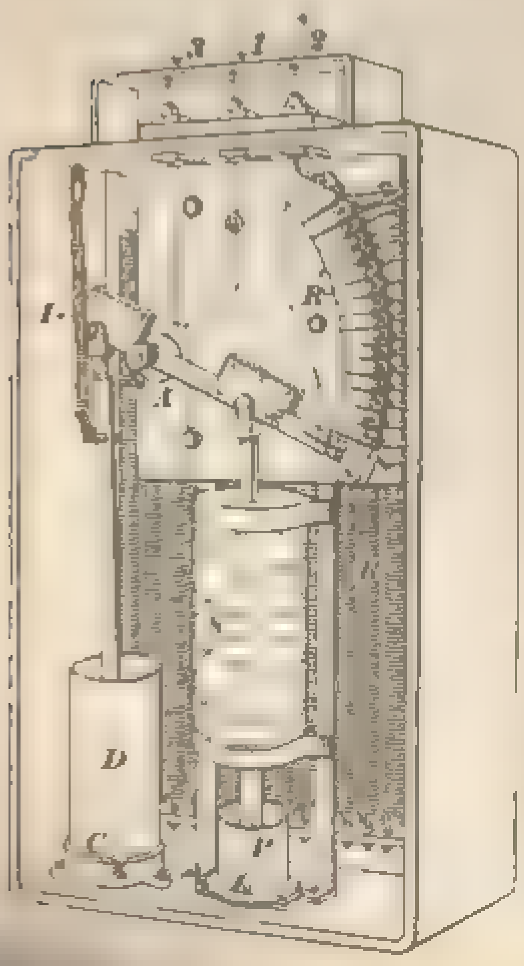


Fig. 7

13. Solenoid Rheostats. — Instead of the weight 9, Fig. 6, a solenoid is used in many starting devices. This permits the rheostat to be mounted separate from the switch, no mechanical connection between the two being required. The switch alone is mechanically operated by the hand rope or other operating device. Fig. 7 shows one form of solenoid rheostat, as manufactured by the Elektron Manufacturing Company. The armature current enters at the binding post *1*, whence it goes to the contact arm *A*, through the series of resistances *R*, and out at the binding

post *2*. The solenoid current, taken from the main switch, enters at binding post *3*, goes through the windings of the solenoid S, and leaves at binding post *2*. As soon as the main switch is closed, the solenoid is energized and draws in the iron plunger P, raising the arm A, and thus making the contact piece at the end slide over the sectors R' of the rheostat and cutting out resistance from the armature circuit. In order that this may be effected gradually, the other end of the arm A is connected by a rod with a piston fitting in a dashpot D. In moving downwards, this piston must displace the air in the dashpot, and the speed with which this may be done is regulated by the stop-cock C. To bring the apparatus back to its original position at the breaking of the circuit, the piston end of the arm is provided with a spring I that is put in tension while the resistance is cut out. On opening the circuit, the spring pulls up the arm and dashpot piston, and in order that this may be effected quickly the dashpot has a relief valve that will open while the piston is going up.

14. The apparatus described in the foregoing articles as applicable to belt-shifting elevators are used for a number of other purposes, among which their connection with electrically driven pumps for hydraulic elevators is of special interest.

DIRECT-CONNECTED ELECTRIC ELEVATORS.

DIRECT-CONNECTED, BELTED ELECTRIC ELEVATOR.

15. The second step taken in the development of the electric elevator was the elimination of the countershaft and the tight and loose pulley, and the substitution therefor of a belt connecting the motor directly with the elevator machine. The mechanisms used in belt elevators for shifting the belt then became superfluous. Although the elimination of the countershaft seems a small and natural step to take, it makes a great change in the working conditions of the elevator,

since in the belt-shifting types the motor starts without load, which is applied only after the motor has attained its normal speed; while in the direct-connected type, the motor must start under load. There is nothing gained by having the motor and the elevator separate and belted together, and therefore direct connected belted elevators are never used; they are described here only to help us to arrive gradually at the form of elevator now commonly used

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DIRECT-CONNECTED ELEVATORS.

16. Connection of Motors and Machines.—The working conditions of the direct-connected belted elevator are not changed when the motor is coupled directly to the shaft of the elevator machine, and in the modern type of electric elevator this is always done, the motor being mounted on the same base with the machine.

17. Motors.—Since in direct-connected electric elevators the motor must start under load and must, therefore, have a strong torque, it must also get up speed rapidly though gradually. Of these two conditions the last-named one is fulfilled by peculiar controlling devices that are described below, while the first-named one is fulfilled by the construction of the motor itself, which is generally of the compound-wound type—a series-field coil serving to give the necessary torque at starting and the shunt coil steadying the field. The series coils are generally cut out when the motor has attained normal speed, after which the motor runs as a simple shunt-wound motor.

Of alternating current motors, only the two-phase or three phase induction motors prove satisfactory for direct-connected electric elevators, since they will start under load with sufficient torque. These motors behave, as far as their action in the elevator combination goes, just like shunt-wound continuous current motors.

18. Transmitting Devices.—The transmitting devices between the motor and car consist, with few exceptions, of

worm-gearing, drum, and rope. The worm-shaft is almost invariably coupled to the motor shaft by a flange coupling, serving at the same time as a brake pulley. Both single worm- and double worm-gearing are used, as will be seen from the illustrations given farther on, the double worm being used mostly on heavy machines, to avoid the end thrust of the worm-shaft. Such heavy machines are also frequently provided with back gearing. Ordinarily, however, single worm-gearing is used, great care and ingenuity being displayed in the design of the step bearings for the worm.

19. Counterbalancing.—Direct-connected electric elevators of the drum type are always overbalanced.

20. Controlling Devices.—The power control of direct-connected electric elevators is entirely electrical, there being no belts to shift or similar mechanical operations to perform; but, besides breaking the current, the motor must be reversed. Hence, besides the simple snap switch and rheostat already mentioned in connection with belt-shifting electric elevators, a **reversing switch** or **pole changer** is needed.

In elevator practice, the complete apparatus necessary to control the electric motor—the **power control,** as we have called it—is called a **controller,** especially if the various parts of it are built together in such a way as to make a separate, self-contained piece of machinery. A number of different forms of such controllers are used by the various manufacturers of electric elevators, and they will be described with the various designs shown.

21. Brakes.—The braking arrangements used are either entirely mechanical, that is, such as are used in connection with belt and steam elevators, or electrical mechanical, or wholly electrical.

22. Operating Devices.—In the majority of electric elevators the operating devices are mechanical, such as hand ropes, hand wheels, and levers. Electrical operating devices

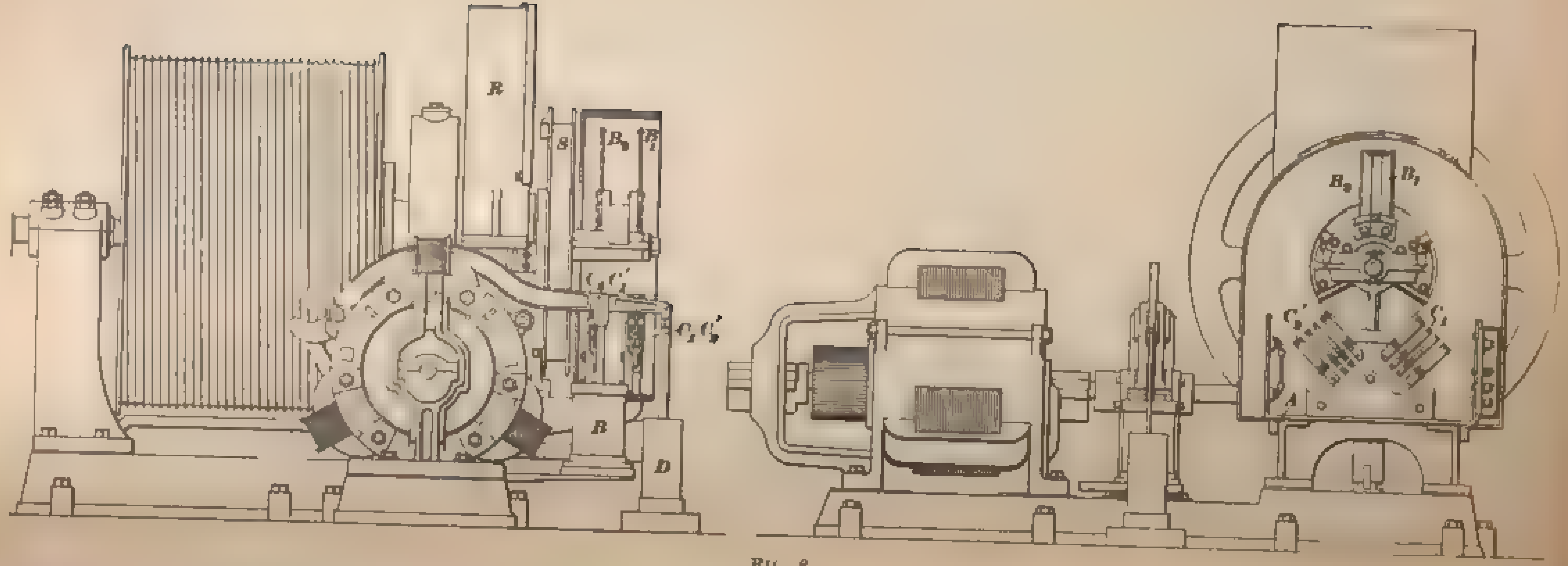


FIG. 8.

are being introduced, however, with success in connection with the magnet system of control, which is described later.

23. Motor Safeties.—Motor safeties are used in various forms; they are either mechanical or electrical or both.

EXAMPLES OF ELECTRIC ELEVATORS.

INTRODUCTION.

24. The examples of electric elevators here given do not represent all the various designs in the market, nor does the order in which they are described indicate any superiority of design of one make over another. A careful study of these will give a person enough insight into the construction and operation of this class of machinery to enable him to handle other makes of machines.

ELEKTRON ELEVATORS.

25. Motors.—Fig. 8 is an end and side elevation of an electric elevator made by the Elektron Manufacturing Company. The motor is the well-known Perret multipolar machine, shunt-wound.

26. Transmitting Devices.—The transmitting devices are single worm-gearing, drum, and rope. The arrangement of the step bearing of the worm is shown in Fig. 9. Alternate phosphor-bronze and steel disks are used to distribute the wear. The worm-shaft is attached to the motor shaft by means of a flange coupling F, which serves at the same time as a brake pulley.

27. Simple Controller.—The Elektron Manufacturing Company uses various kinds of controllers for various kinds of elevators. The simplest arrangement used is a double-throw switch attached to the hub of the shipper sheave S, Fig. 8, and a solenoid rheostat placed anywhere conveniently

near the machine; such a rheostat is shown in Fig. 7 and another form in Fig. 10.

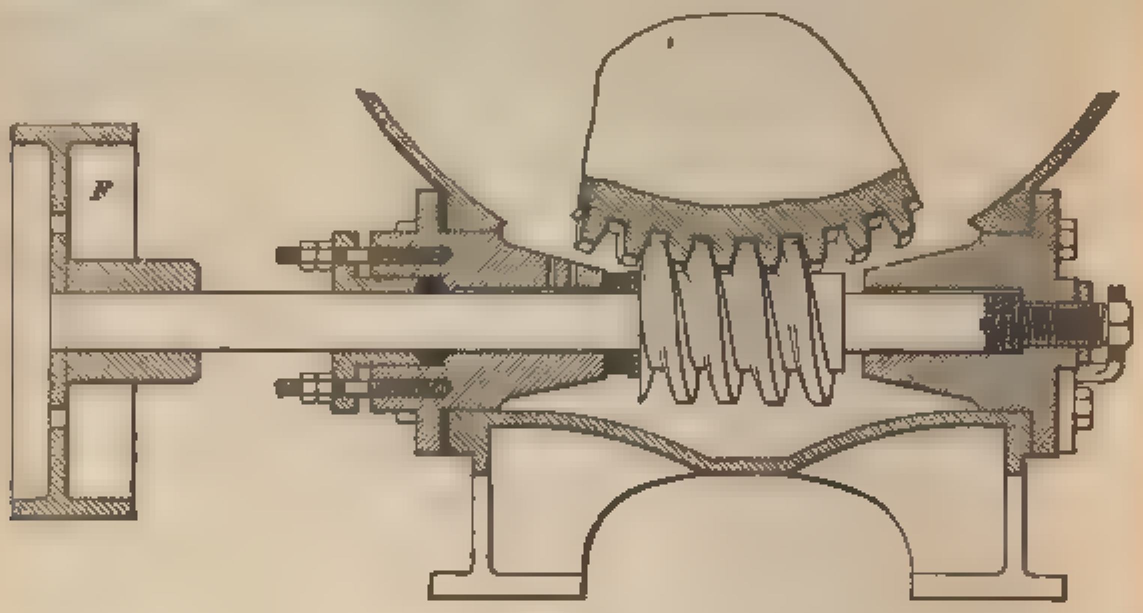


Fig. 9

The switch consists of a casting A, Fig. 8, supported on the frame of the machine and carrying four sets of clips C_1, C_2, and C_1', C_2', to which the necessary line, field, armature, solenoid, and electric-brake connections are made as shown below. The switch blades B_1, B_2 attached to the shipper sheave engage the clips C_1, C_2, or C_1', C_2' for the up trip and the down trip, respectively. In Fig. 8 the blades are shown in their neutral position; that is, when the elevator is at rest. It will be seen that to start the elevator up or down, the sheave with the blades must be turned through an arc of 135°, the clips being set at right angles. This long travel is given for the purpose of giving the rheostat arm time to fall back into its starting position before the current in the armature can possibly be reversed; it also helps to reduce sparking and flashing at the clips.

28. Ordinary Brake.—The brake used in these machines is, for ordinary service, a simple mechanical one, which is released by a cam on the shipper sheave through a system of levers and applied by a weight, as with belt elevators. For passenger service, an electrical mechanical brake is used, which is released by an electromagnet and applied by gravity. This arrangement is shown in Fig. 8, in which

the brake magnet is marked *B*; the rapidity of action of the same is regulated by a dashpot *D*.

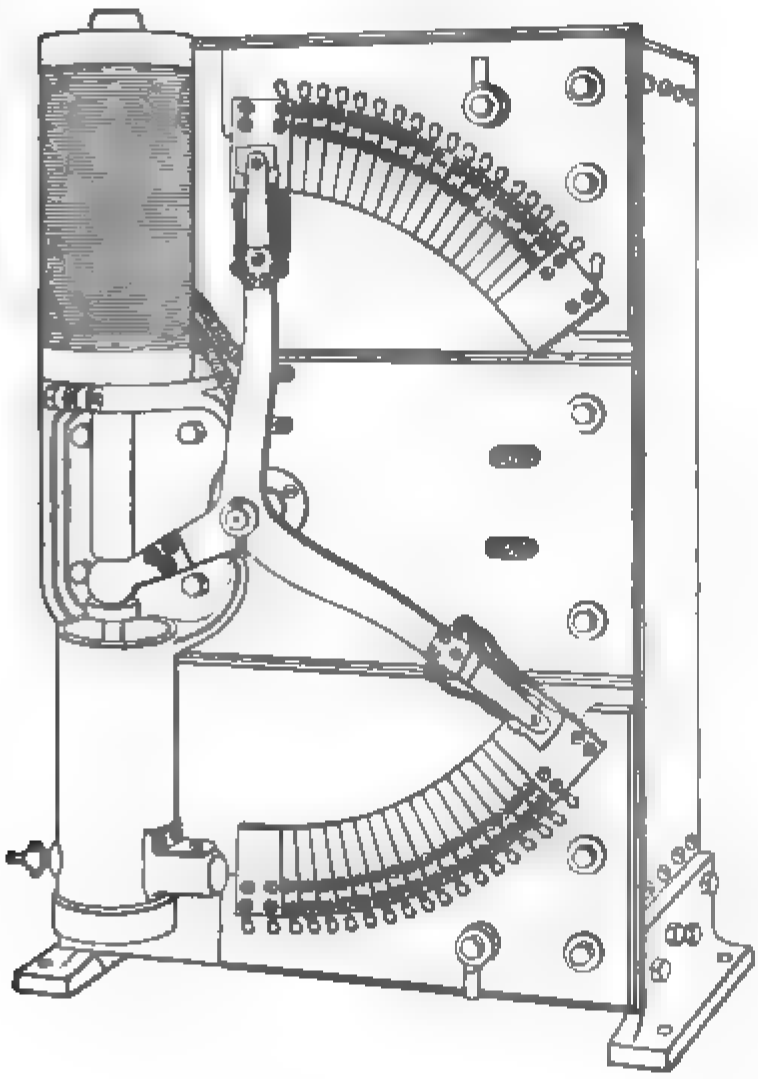


FIG. 10.

29. Fig. 11 is a diagram of the electrical connections between the switch, rheostat, brake, and motor. It will be useful to follow out these connections. The lines are connected through the fuses *f*, *f* and the double-pole switch *s* to the elevator switch at the binding posts L_4 and L_7. Supposing the blades of the switch to be thrown to the right, that is, across the clips C_1 and C_2, and the current to enter at the binding post L_7, then it passes first to clip *1* of the set C_1, whence it divides by means of the switch blade among the clips *2*, *3*, and *4*. From *2* it passes to binding post L_8, thence through the field windings of the motor, back to the binding post L_4, thence to the clip *b* of set C_2,

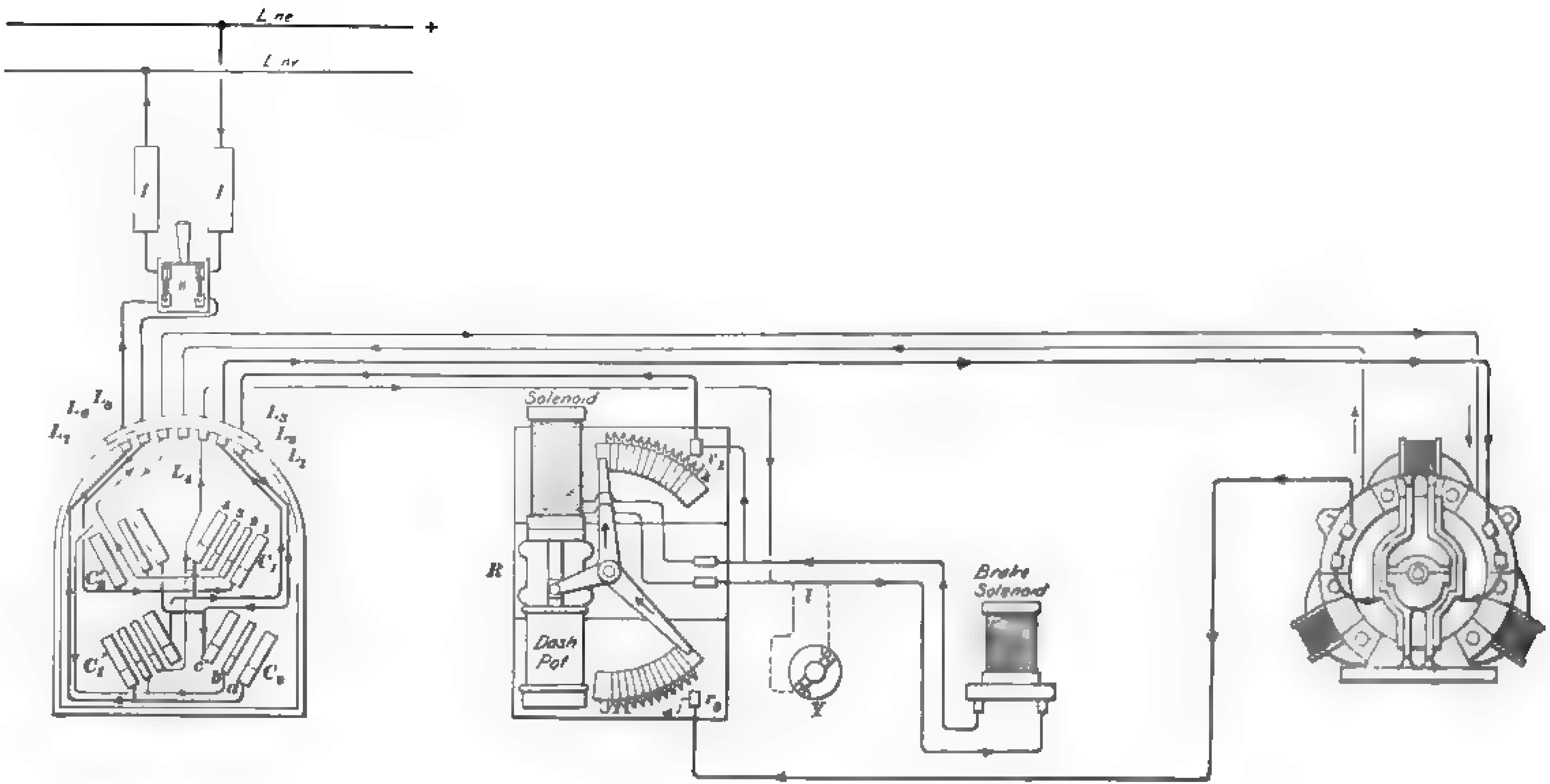


FIG. 11.

over the blade crossing this set of clips to clip *a*, thence to binding post L_7 and to the line, thus completing the shunt circuit for the field. From clip *3* the current goes to the binding post L_3, through the solenoid windings of the rheostat *R* to the binding post r_1 of the rheostat to the binding post L_1 of the switch, to clip *c* of set C_2 over the blade to the clip *a*, to the binding post L_7 to the line, thus completing the circuit through the solenoid. From clip *4* the current goes to binding post L_2, thence through the armature of the motor to the binding post r_2 of the rheostat, through the lower half of the resistance, through the rheostat arm and the upper half of the resistance to binding post r_1, to L_1, *c*, *a*, L_7, and line, thus completing the armature circuit. Throwing the blades to the left, we will find, in following out the three circuits again, that the current traverses the field circuit in the same direction as before, but that the current in the armature is reversed, thus reversing the motor. The electromagnet windings of the brake are in shunt with the solenoid circuit, as is easily seen from the diagram.

30. The operation of this elevator is as follows: When the shipper sheave is thrown over to the right or left, the brake magnet is energized and tends to slowly release the brake, since the dashpot prevents too sudden a release; at the same time the solenoid is energized. This tends to slowly cut out the resistance from the armature circuit; the dashpot prevents too quick an action, and it is so adjusted that all the resistance will be cut out by the time the motor reaches its normal speed. Upon breaking the circuits, the brake is at once applied and the resistance arm drops back into its original position, ready for another start.

31. Dynamic Brake.—On high-speed elevators, in order to get a particularly smooth stop, the Elektron Manufacturing Company uses, in addition to the electrical-mechanical brake, a so-called dynamic brake, which, indicated in Fig. 8 at *R*, is usually placed on a bracket between the shipper sheave and worm-gear case. It is shown in

detail in Fig. 12 and consists of a switch lever L, actuated by a cam on the operating sheave, and a variable resistance

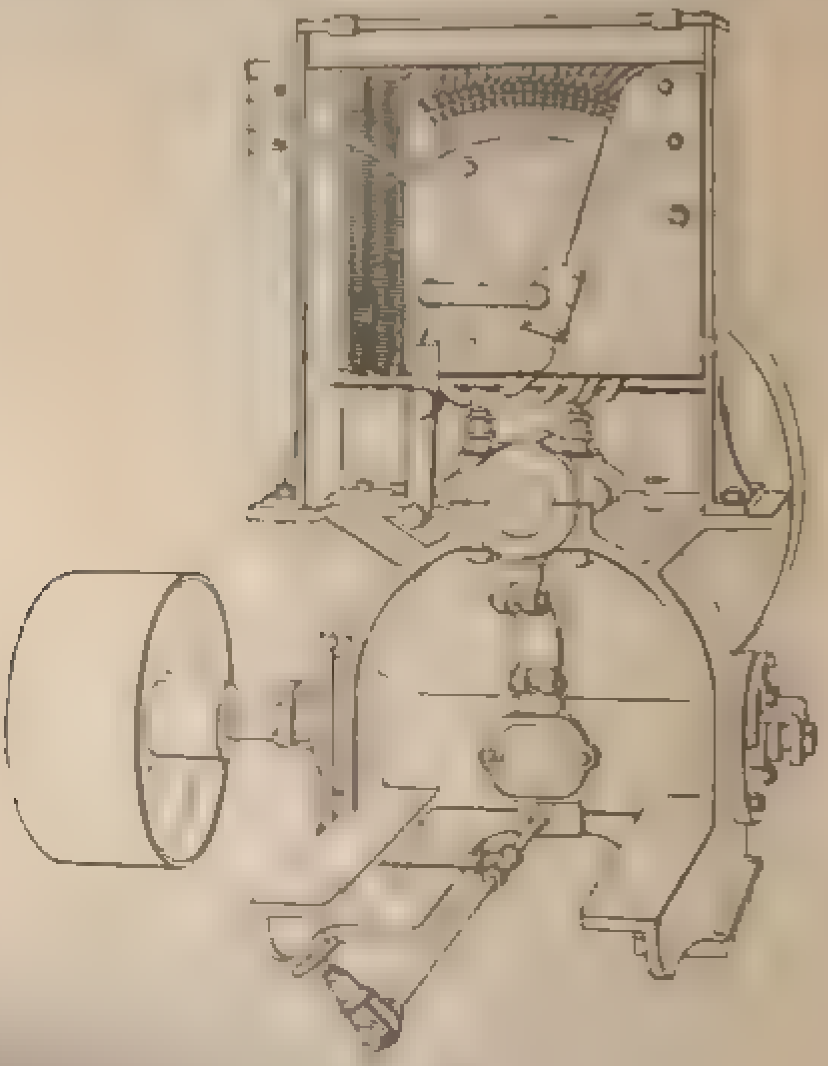


Fig. 12

This resistance is so connected to the system that the armature is short circuited through it immediately after the circuit [illegible] is broken to stop the elevator, thus acting [illegible] the motor acting as a dynamo and [illegible] through the resistance. This has the [illegible] down quickly but smoothly, like a [illegible] than an ordinary frictional brake. [illegible] is made still more marked by [illegible] gradually cut out of the armature short [illegible] down, the cam operating the [illegible] as to first cut in all the resistance [illegible] main circuit is broken, on being [illegible] the operator, the switch lever is caused to

brush over the resistance contacts, thus gradually cutting the resistance down to zero. Of course this short circuit is opened before the elevator is started again. As has been said, the dynamic brake is used only in addition to the ordinary brake, the latter being necessary to hold the car stationary after it has been stopped.

32. Fig. 13 shows diagrammatically the connections when the dynamic brake is used. The field must necessarily remain excited after the armature circuit is broken and the armature short-circuited, in order to make the motor act as a dynamo. The field is, for the sake of simplicity, kept excited all the time, but in order to cut down the current thus constantly wasted while the elevator is standing still, a resistance is inserted in the fields. When the elevator is started, this resistance is short-circuited, thus giving the fields the full current due to its windings and, consequently, the full torque available. When the elevator is stopped, the resistance is cut in, choking the field current, but leaving it strong enough to give sufficient magnetism to get a dynamic-brake effect.

33. Speed Regulating Controller.—Another type of controller used by the Elektron Manufacturing Company is shown in Figs. 14 and 15, while the diagram of connections is given in Fig. 16. It is evident that the combinations described in the previous article do not allow of any regulation of speed, the motor being simply shunt-wound with an unchangeable field. The purpose of the arrangement now to be described is to give speed regulation, which is accomplished by a changeable resistance in the field. The controller is mechanically operated.

As seen in Fig. 14, there are two cams *I* and *II* operating the armature and field-resistance arms A_a and A_f, respectively. Both arms are provided with dashpots D_a and D_f. Two more cams *III* and *IV*, shown in Fig. 15, operate the reversing switch, or pole changer, *P*; the one cam is intended to throw the switch for going up and the other for going down. While not visible in the illustrations, there

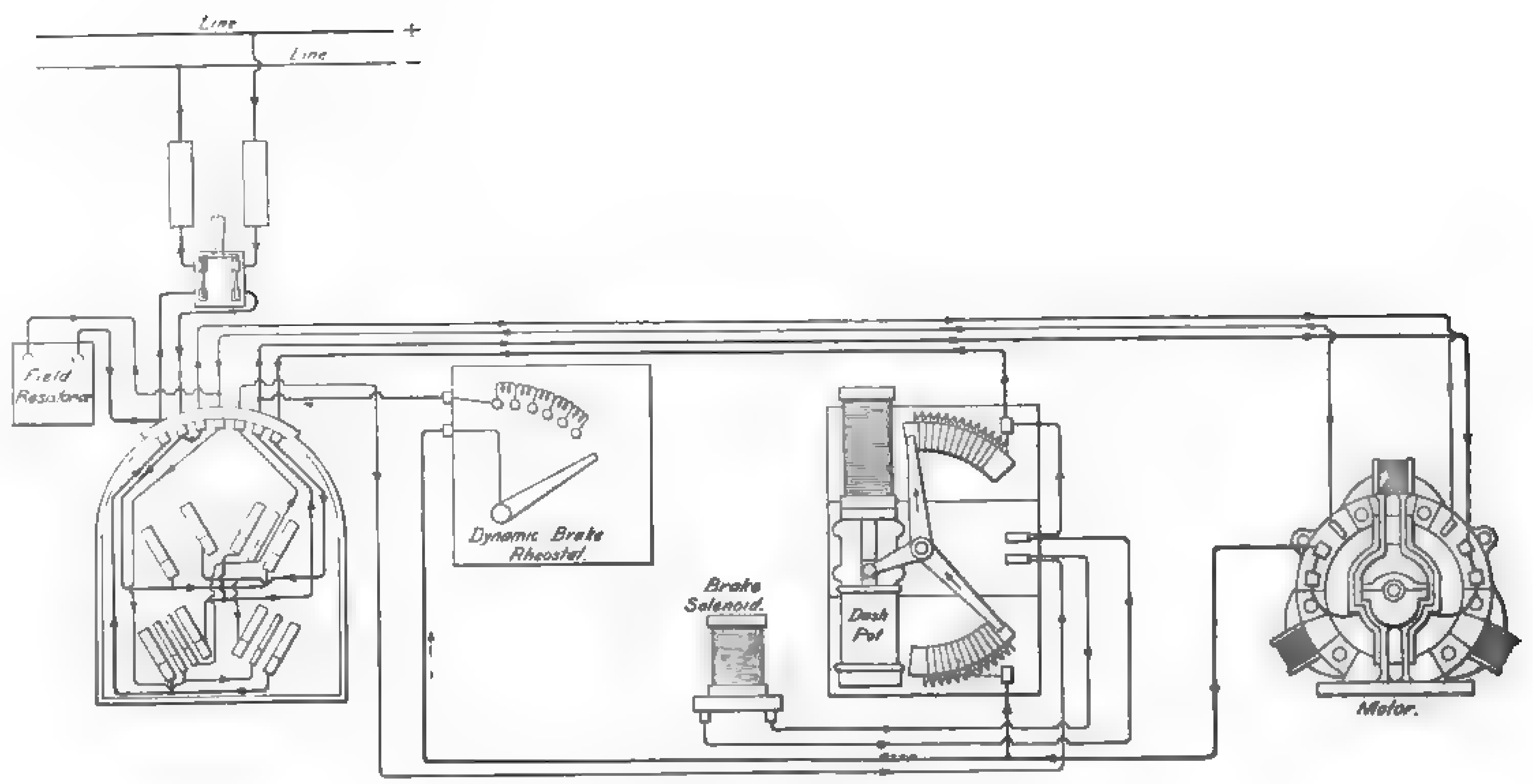

Line
+
Line
−
Field Resistance
Dynamic Brake Rheostat.
Brake Solenoid.
Dash Pot
Motor.

FIG. 18.

are other cams that operate various knife switches. All these cams are mounted on the shipper-sheave shaft S. The brake is the same as in the previous design

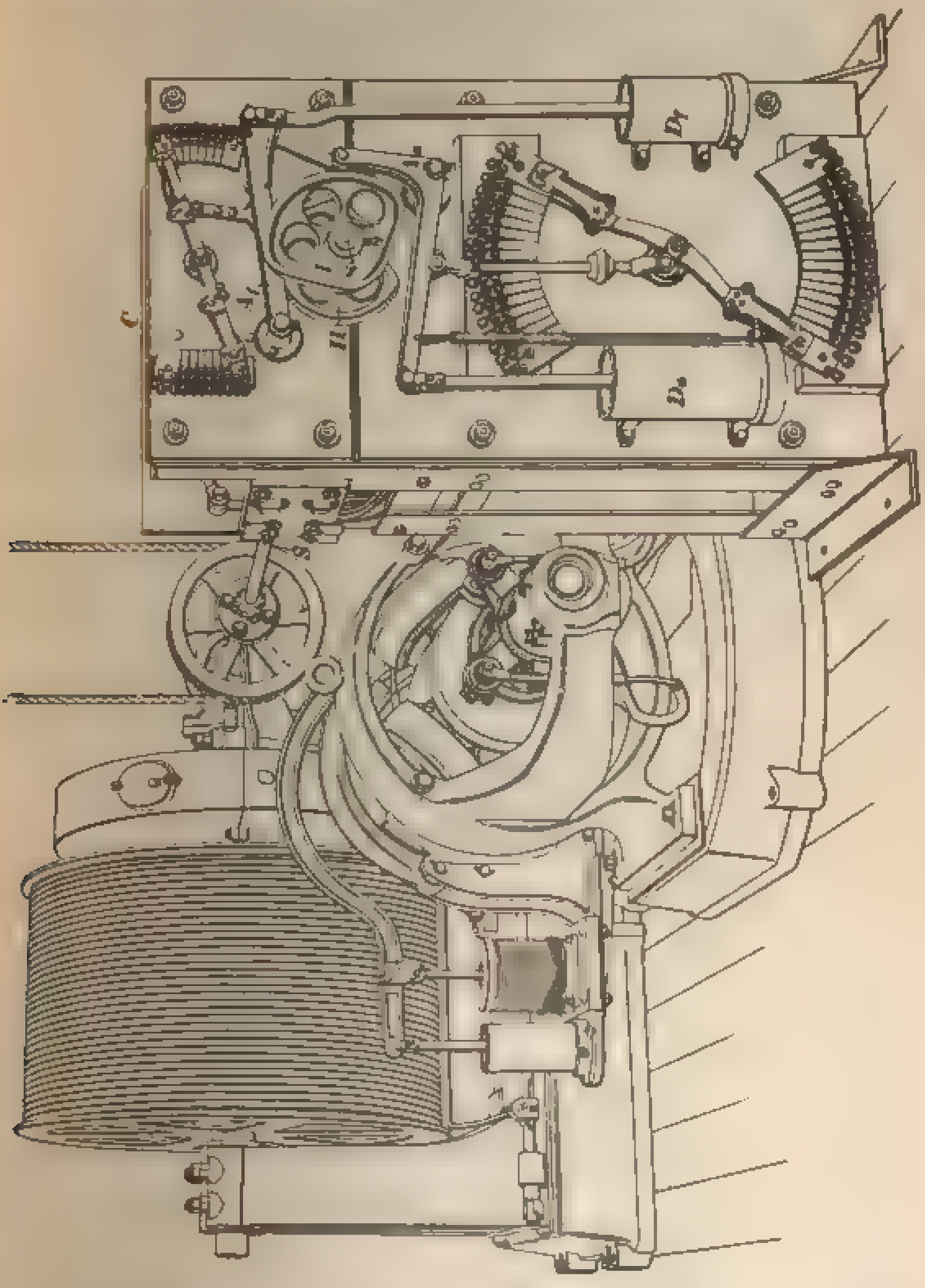


FIG. 14.

34. Fig. 16 is a diagram of the connections for this controller (*a*) shows the external connections between motor, brake, and connection board B; (*b*) gives the internal

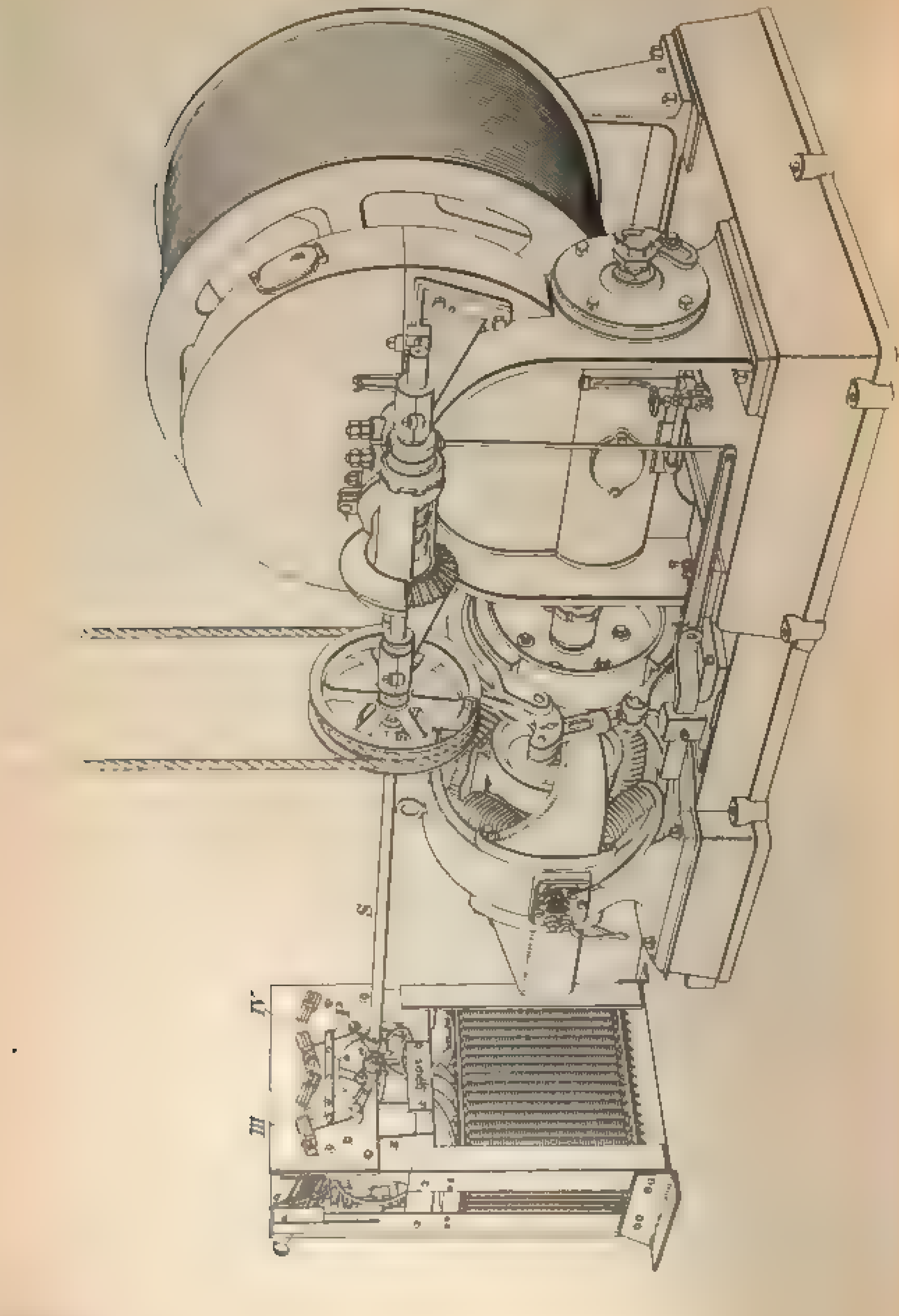


Fig. 15.

connections between the connection board B and the various clips and resistance blocks inside the controller. By swing-

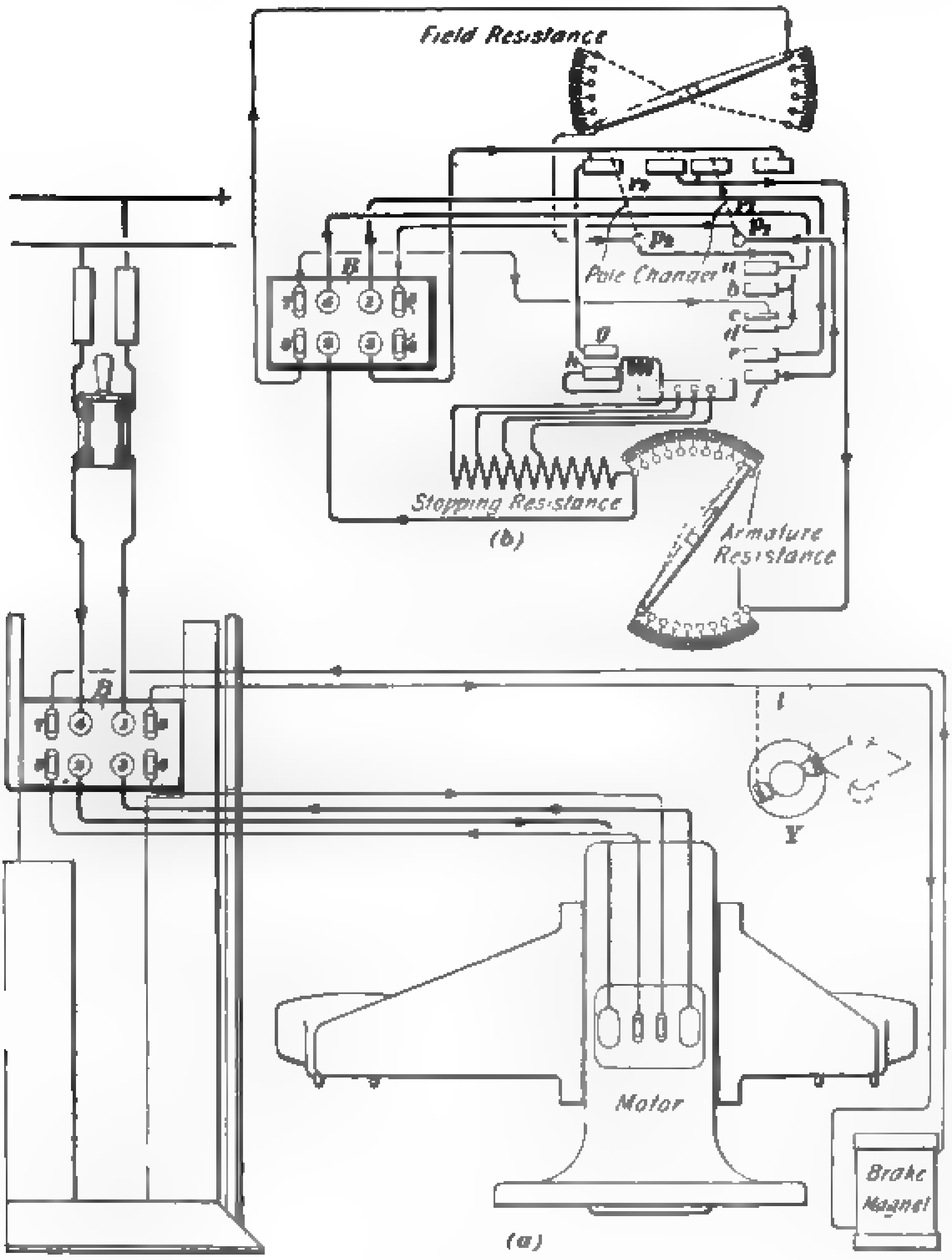


FIG. 16.

ing the shipper sheave to the right or left, switch blades connect the clips a and b, c and d, and e and f, completing the

circuits. Thus, supposing the current to enter the system from the line at the binding post *1*, it goes to the clip *e*, over a blade or knife to the clip *f*, thence to the pivot p_1 of the pole changer, where it divides. One branch goes through the pole-changer arm r_1 and the armature resistance to binding post *2*, thence through the armature back to the binding post *3*, thence through the other pole-changer arm r_2 to the pole-changer pivot p_2, to the clip *b*, over the knife to the clip *a*, thence to the binding post *4*, and back to the line, thus completing the armature circuit. The other branch of the circuit goes from p_1 to the binding posts *5* and *6*, which, in turn, are connected, respectively, to the brake-magnet circuit and the shunt-field magnet circuit. The other terminal of the brake-magnet circuit is connected to the binding post *7*, whence the current flows over clips *c* and *d*, and *b* and *a* to the binding post *4*, and back to the line. The other terminal of the field circuit is connected to the binding post *8*, whence the current flows through the field resistance to p_2, *b*, *a*, post *4*, and back to the line.

35. The cam *I*, Fig. 14, on the shipper-sheave shaft is so arranged that after the circuits are closed the armature-resistance arm A_a is free to move, which it does slowly under the retarding influence of the dashpot D_a, gradually cutting out resistance until at the normal speed of the motor all resistance is cut out. After turning the shipper sheave a little farther, the cam *II* controlling the field-resistance arm A_f is released, but is retarded by the dashpot D_f. Thus the field resistance is slowly *cut in*, weakening the field and speeding up the motor.

36. Another pair of clips *g* and *h*, Fig. 16, is so connected that when a switch blade is thrown across them, the armature is short-circuited through the stopping resistance. This switch *g h* is closed and the armature short-circuited when the other circuits are opened.

37. Motor Safeties.—The usual motor safeties, viz., limit stops and slack-cable safety, such as we have met in

connection with belt and steam elevators, are used in the Elektron elevators. Their arrangement is shown in Fig. 15.

38. Another motor safety used is in the shape of a switch controlled by a centrifugal governor running in unison with the car, and which opens a switch in the brake circuit when the car attains undue speed. This safety is indicated at *Y* in Figs. 11 and 16, and is connected in series with the brake solenoid by opening the solenoid circuit at point *l* and inserting switch *Y*, as indicated by the dotted lines.

SEE ELECTRIC ELEVATORS.

39. Motors.—Fig. 17 shows one of the standard machines built by the A. B. See Manufacturing Company. A bipolar, drum-armature, compound-wound motor is used.

40. Transmitting Devices.—Among the transmitting devices, the step bearing shown in Fig. 18 is of peculiar construction. Both steps, that for the up trip and that for the down trip, are located at the free end of the worm-shaft and are easily accessible. The one is adjustable by means of the plug *P* in the cap *C*, while the other is made so by means of the nut *N* on the threaded free end of the shaft. The other end of the worm-shaft passes through a stuffingbox *S*, as in other machines. The worm and lower part of the worm-wheel are constantly running in oil.

41. Controller.—The controller, as shown in Fig. 17, is placed on top of the motor and consists of a box with three compartments, one of which is accessible from doors *O*, and another one from similar doors on the opposite side. The first, shown open in Fig. 19, contains the main reversing switch *M* and three snap switches *N*, *N'*, and *U*, the blades, or knives, of the latter being mounted on the same lever, but insulated from one another. The switches are operated by a bar *B*, which, in turn, is linked to the rack *R*, Fig. 17, and operated by a pinion *P* fastened to the shipper sheave *S*. The opposite compartment contains a solenoid dashpot, a

resistance lever, and resistance contacts very much the same as those shown in Figs. 7 and 10. The third compartment is located between the first named two and contains resistance coils of German-silver wire. The walls of the compartments

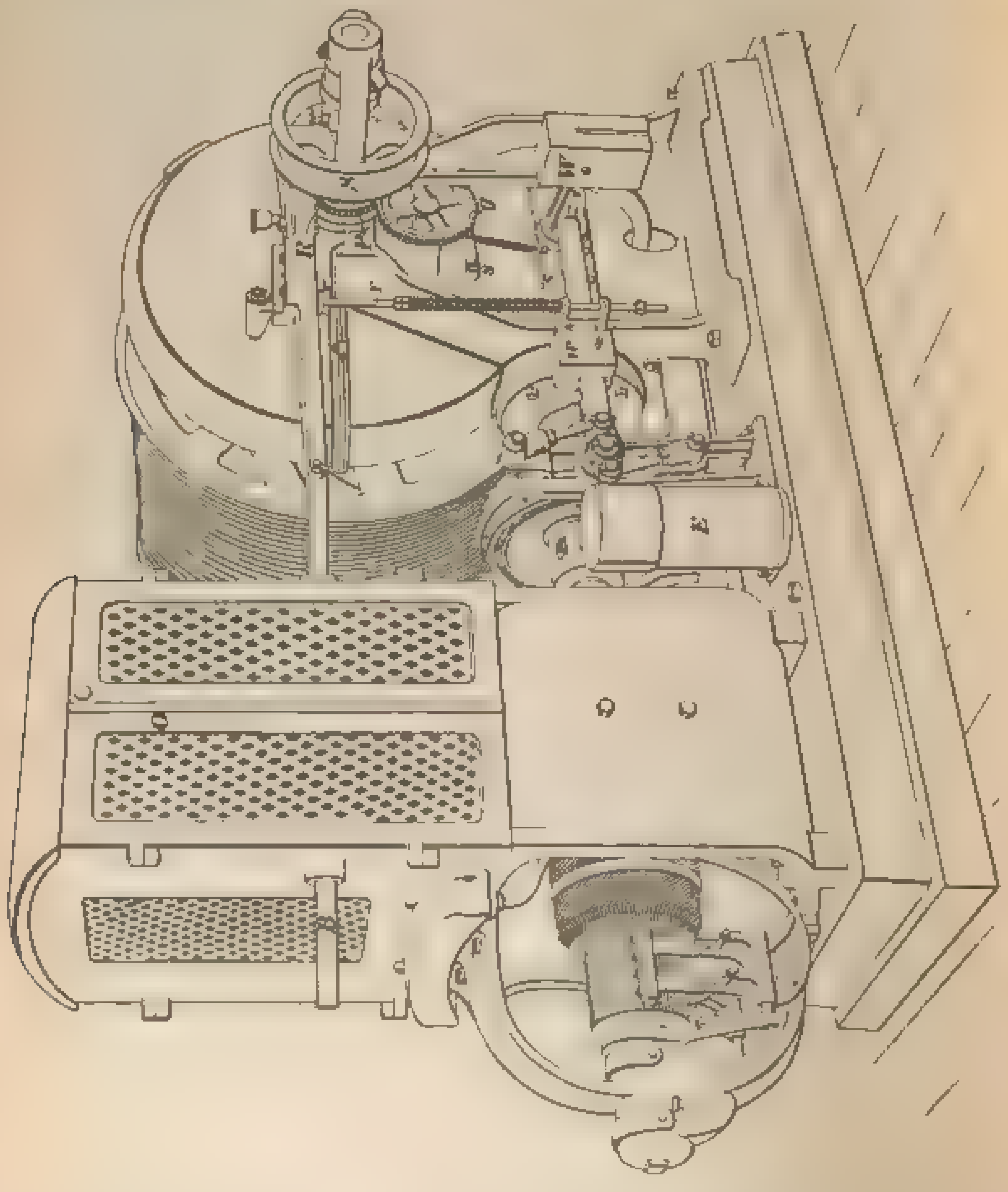


FIG. 17.

are cut away wherever they are not needed for the support of contacts or mechanisms, so as to give ventilation to the resistance coils; the doors and sides of the controller are perforated, as shown in Fig. 17, for the same purpose.

42. Brake.—The brake used in this machine is controlled mechanically and electrically. A spring-cushioned push rod *r*, Fig. 17, is operated by an arm fastened to the shipper sheave and forces the brake lever down to apply the

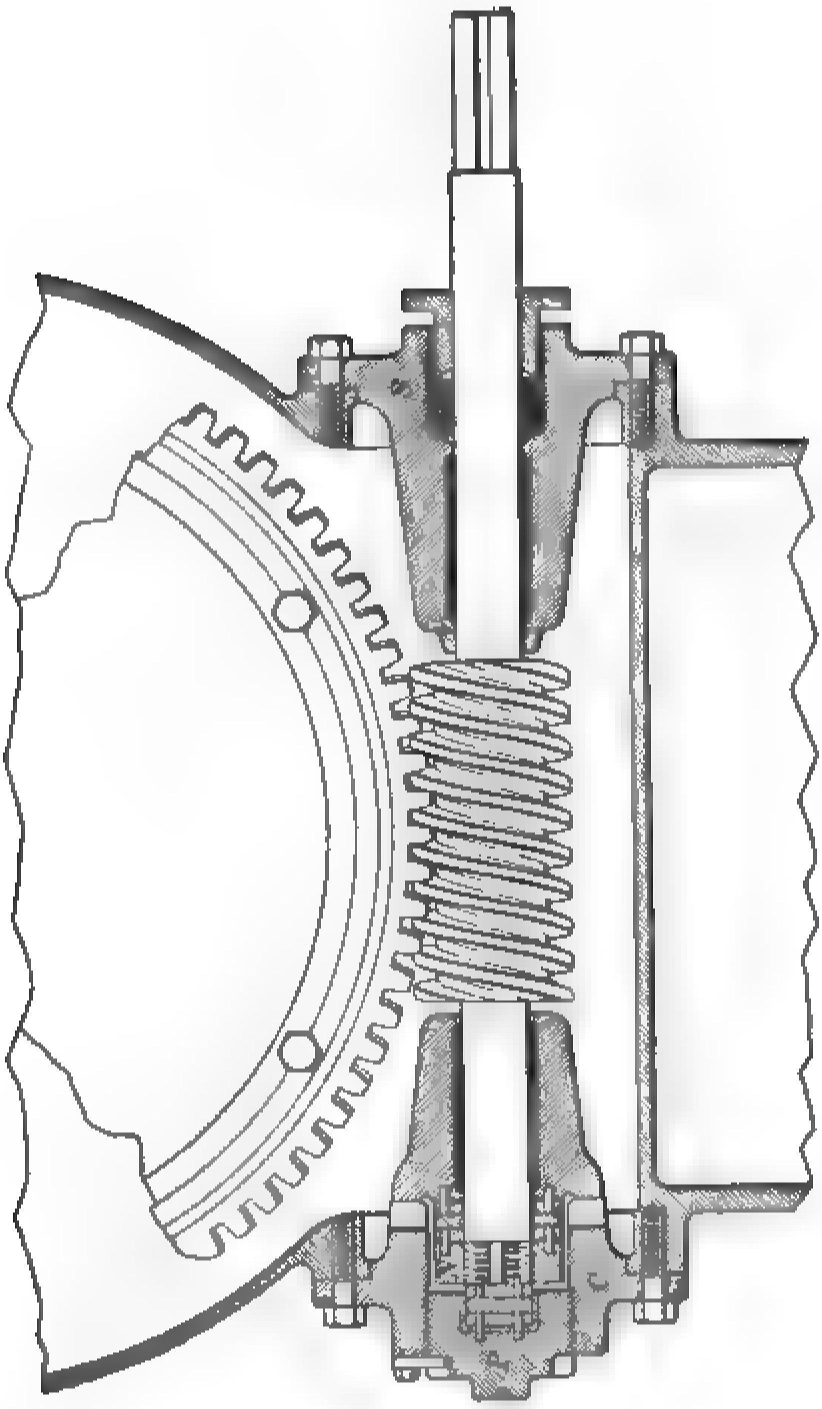


FIG. 18.

brake. A solenoid *E* holds off the brake as long as there is current in the armature with which the solenoid is connected in series. A weight *W* applies the brake, when the current is broken. There is also a dynamic-braking effect, the

armature being short-circuited through resistance when current is shut off from the machine.

43. Motor Safeties.—This machine is particularly well provided with motor safeties. Not only the usual traveling-nut, limit-stop, and clutch-operating slack-cable safety are provided, but an extra limit switch is also provided, which breaks the current through the armature and brake solenoid

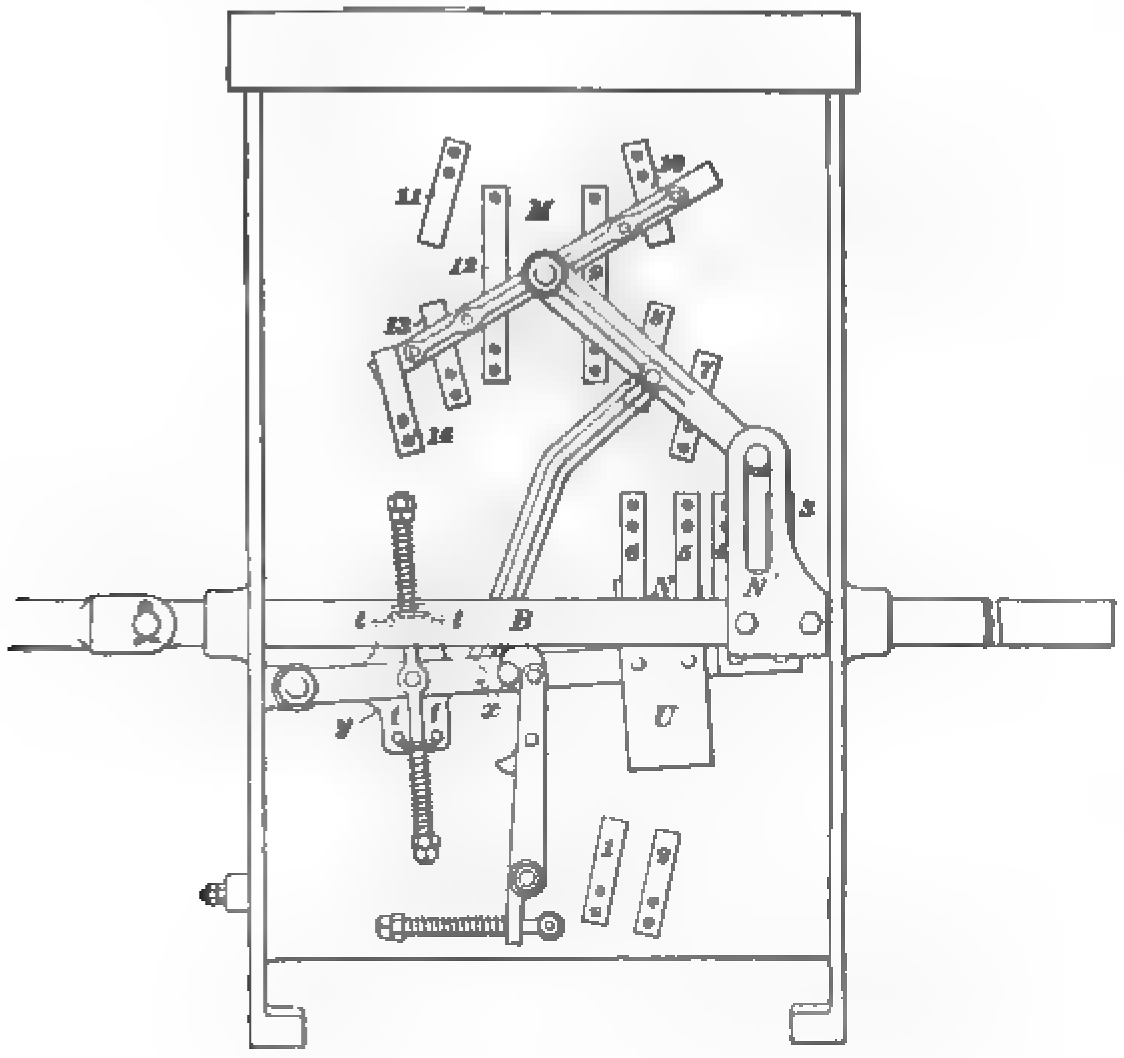


FIG. 19.

at the limits of car travel. This switch *s*, Fig. 17, located on the worm-gear casing below the drum shaft, is spring actuated and tripped by a stop on a gear *g*, which is one of a suitable train of gears driven from the drum shaft. The weight *W* throws in the clutch that connects the drum shaft with the shipper sheave when it is tripped by slack cable.

44. Electrical Connections.—Fig. 20 is a diagram of the electrical connections. The contact pieces are marked in the diagram the same as in Fig. 19. The circuits for the position of the controller shown in this figure are as follows.

45. *Armature Circuit.*—In the armature circuit the current passes through the + line to clip *3*; from clip *3* to clip *4* over the blade of the switch; from clip *4* to clip *19*; and from clip *19* to clip *18* over the switch blade, which is open only when the car overtravels the normal limits of travel; from clip *18* the current passes through the series coil of the electric brake to clip *5* and then to clip *6* over the switch blade; from clip *6* it passes through the series field of the motor, through the armature resistance and series coils on the armature resistance solenoid to clip *10* and then to clip *9* through the switch blade; from clip *9* it passes through the armature to clip *12*; from clip *12* to clips *13* and *14*; from clip *14* to clip *7*; and from clip *7* to the — side of the line.

46. In the armature circuit, when the pole changer is reversed from the position shown in Fig. 19, the current passes from the + line to clip *3* and then to clip *4*; from clip *4* to clip *19* and then to clip *18*; from clip *18* to clip *5* and to clip *6*; from clip *6* to clip *10* and on to clip *11*; from clip *11* to clip *12* and then through the armature, in a reverse direction, to clip *9* and then to clip *8*; from clip *8* to clip *7* and then to the — side of the line.

47. *Dynamic-Brake Circuit.*—When the controller is in its neutral position, that is, when the current is shut off from the machine, clips *1* and *2* are bridged by the switch blade *U* and the motor is short-circuited through the resistance, passing from clip *1* through the armature and then through the short-circuit resistance *a* to clip *2*.

48. *Electric Brake.*—The shunt coil of the electric brake obtains its current from clip *17*, clips *17*, *18*, and *19* being bridged by one switch blade, which is operated by the stop motion mentioned in Art. **43** and which stop motion

automatically breaks connection between clips *17*, *18*, and *19* when the car overtravels its normal limits. This switch is essentially an automatic safety switch, for it not only breaks the line current before it passes through the armature, but also breaks the current flowing through the shunt coils of the brake solenoid.

The + side of the shunt coil is connected to the separate clip *17* instead of to the clip *18* in order that upon breaking the circuit the armature circuit may be disconnected from the electric-brake circuit, thus allowing the brake to act at once. Otherwise, the motor still running would send enough current through the shunt coil of the brake solenoid to keep it energized and thus prevent its action. The electric-brake circuit is, therefore, from clip *17* through the shunt coil to the terminal *M'*, and from *M'* to clip *8* or *13*; from clip *13* to clip *14*, or from clip *8* to clip *7*, and thence to the − side of the line.

49. *Path of Current in Starting Box.*—The shunt coil of the solenoid *D*, Fig. 20, gets its current from clip *5*; and after the current passes through the coil it enters clip *21*. The switch blade, or knife, that bridges clips *20*, *21*, *22* is drawn out of contact with the clips when the plunger of the solenoid reaches the end of its travel, when all the resistance in the armature circuit is thus cut out. Before the switch blade is removed, the current crosses on it to clip *22*; from clip *22* it passes to clip *16*, and thence to clip *7*, whence it goes to the − side of the line.

When the contact is broken, the current is forced to pass from clip *21* to and through the resistance *d* from the terminal *M''* to the terminal *S*; from the terminal *S* it passes to the terminal *M'*, then to clip *8*, and so on to the negative side of the line. The resistance *d* is introduced in this circuit for the purpose of reducing the heating in the shunt coil and to reduce the current consumption after the solenoid has done its maximum work.

50. *Field.*—The field circuit of the motor is as follows: The current passes from the + line to clip *3* and thence

through the field to the terminal *F* of the resistance *d*. From *F* it passes to clip *20* and thence to clip *22*, to clip *16*, to clip *7*, to the negative side of the line. When the armature resistance is all cut out, contact between clips *20*, *21*, and *22* is broken, and the current is forced to pass through the portion of the resistance between the terminals *F* and *S* to the negative side of the line, provided the parallel connections from clip *15* to clip *16*, or at the limit switch from clip *23* to clip *24*, are broken. This resistance weakens the field on the motor and causes it to run at a higher speed. The contact between clips *23* and *24* is automatically made and broken when the car gets within about a floor from the top or bottom of its travel, and by the same stop motion that operates the limit switch. When the switch blade connects clips *23* and *24*, the resistance in the field is short-circuited; the field strengthens and the motor slows down. The switch blade bridging clips *15* and *16*, although situated at the machine, is withdrawn directly by the operator in the car during the last few inches of travel of his controlling lever, and he is thus enabled to weaken the field on the motor and run at a higher speed, but only after the car passes the first floor from the top or bottom and after all the resistance is cut out of the armature circuit.

51. In some of the See machines, the field is broken every time the motor stops. Fig. 20 is a diagram of a machine where the field is *on* all the time. Whether the field is to be left on or off is determined by the duty of the elevator. When the high-speed attachment is left off, a change in connections from those shown in Fig. 20 is made, Fig. 20 being a diagram of connections for a high-speed elevator running 250 feet per minute and over.

OTIS ELECTRIC ELEVATORS.

52. Motor.—The Otis Elevator Company makes a number of styles of electric elevators. They are all of the drum type, but have various kinds of controlling devices. Figs. 21

and 22 illustrate what may be termed the standard type of Otis elevators.

The motor used is the Eickemeyer bipolar, drum-armature, compound-wound type, the series coils of the field being

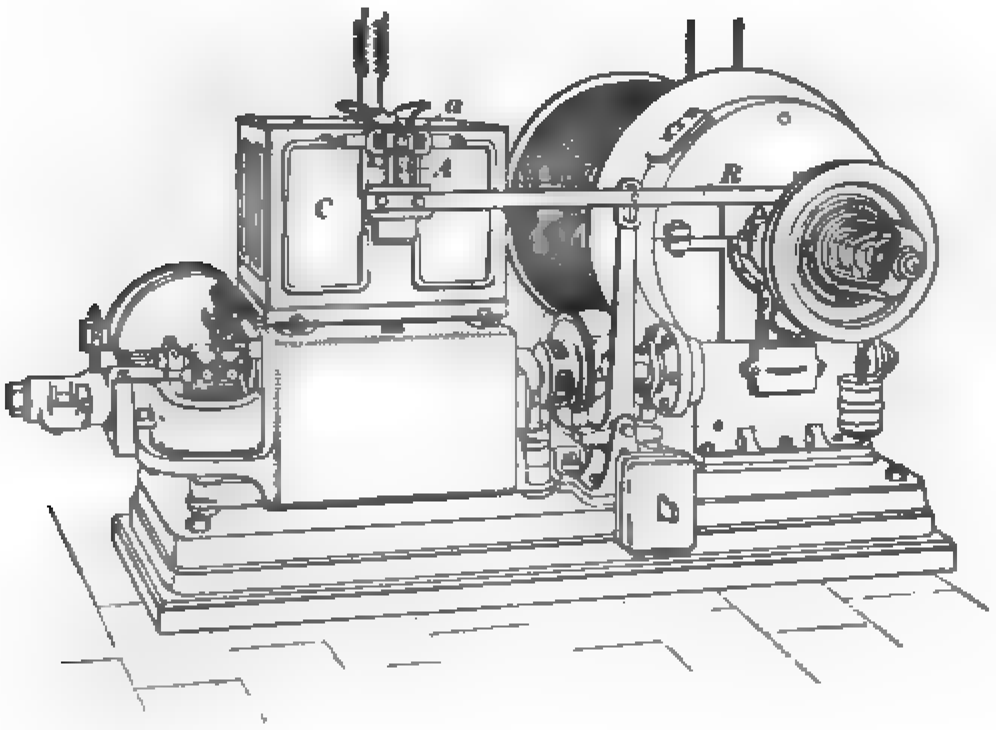


FIG. 21.

cut out after the starting resistance has all been cut out, that is, when the motor has acquired normal speed. This is done both on the up and down trip of the car.

53. Transmitting Devices.—With regard to the transmitting devices, it may be mentioned that either single or double worm-gearing is used, the latter for the larger sizes generally. In connection with the single worm a peculiar kind of step bearing is used. The purpose of this arrangement, shown in Fig. 23, is to increase the bearing surface, without enlarging the diameter of the step, by dividing the pressure between two surfaces, viz., the end surface *s* of the shaft and the ring-shaped surface *s'* of the bushing *B*. Now, it is well known to any mechanic that it is next to impossible to make the wear equal on two such separate surfaces unless special provision is made for it. This provision consists in this case of a couple of small levers *l*, *l* having three

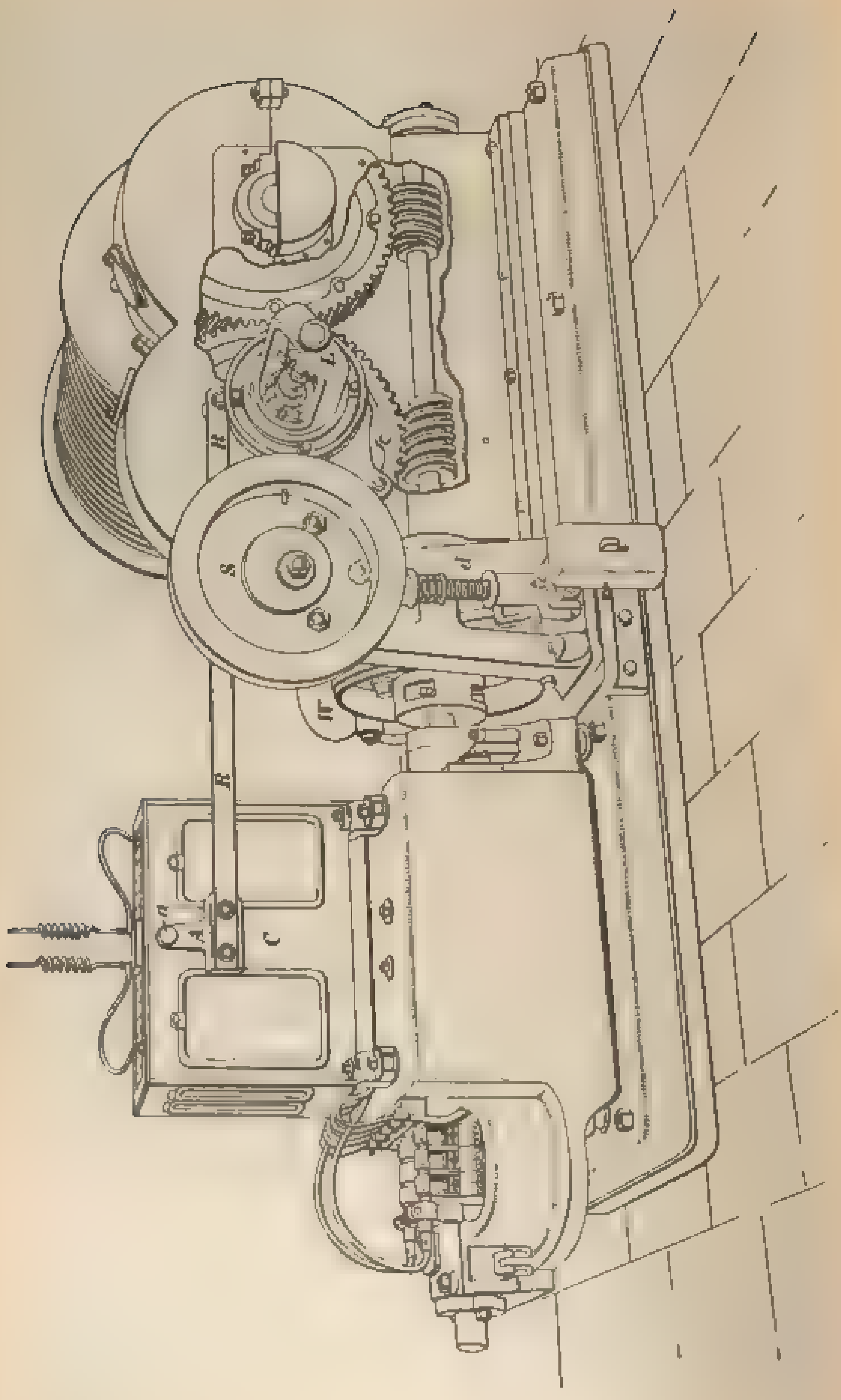


FIG. 21

points each. One of these points, in the middle of one side of the lever, rests against an adjusting screw *S*, which is provided for the purpose with a circular groove. Of the other two points on the ends of the other side of the levers, one rests on the step plate *P* and the other on the bushing *B*. If the bushing wears faster at *s'* than the step plate wears at *s*, the shaft will move to the right, which will cause the levers to press on the bushing, and vice versa. Thus, the pressure is equally distributed over both surfaces *s* and *s'*. The screw *S* serves to take up the wear. The little equalizing levers *l*, *l* are held in place by being placed in slots in the sleeve or bushing *B*, and by a pin *p* that fits into semicylindrical grooves in the end of the levers. Buffers between the worm-gear and drum are used on all Otis electric elevators to absorb vibration.

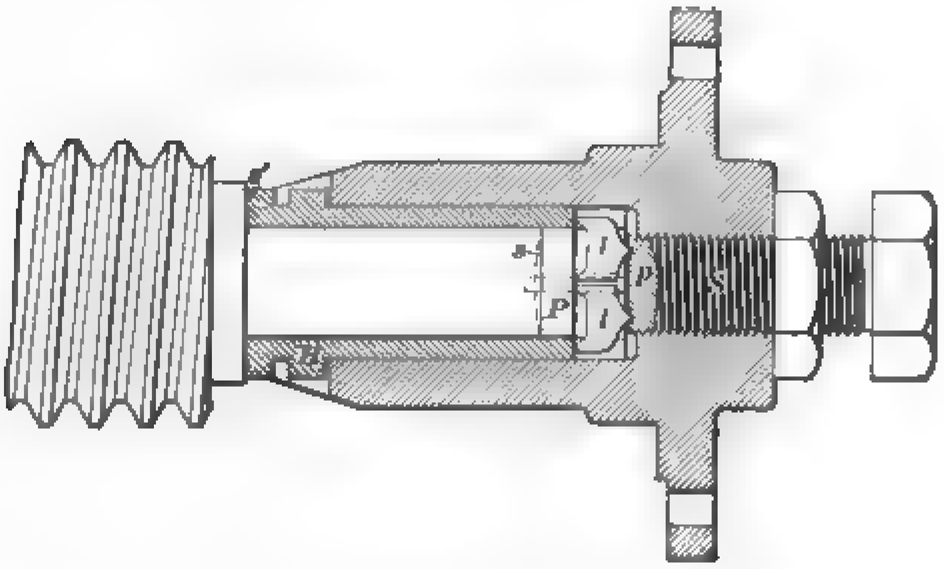
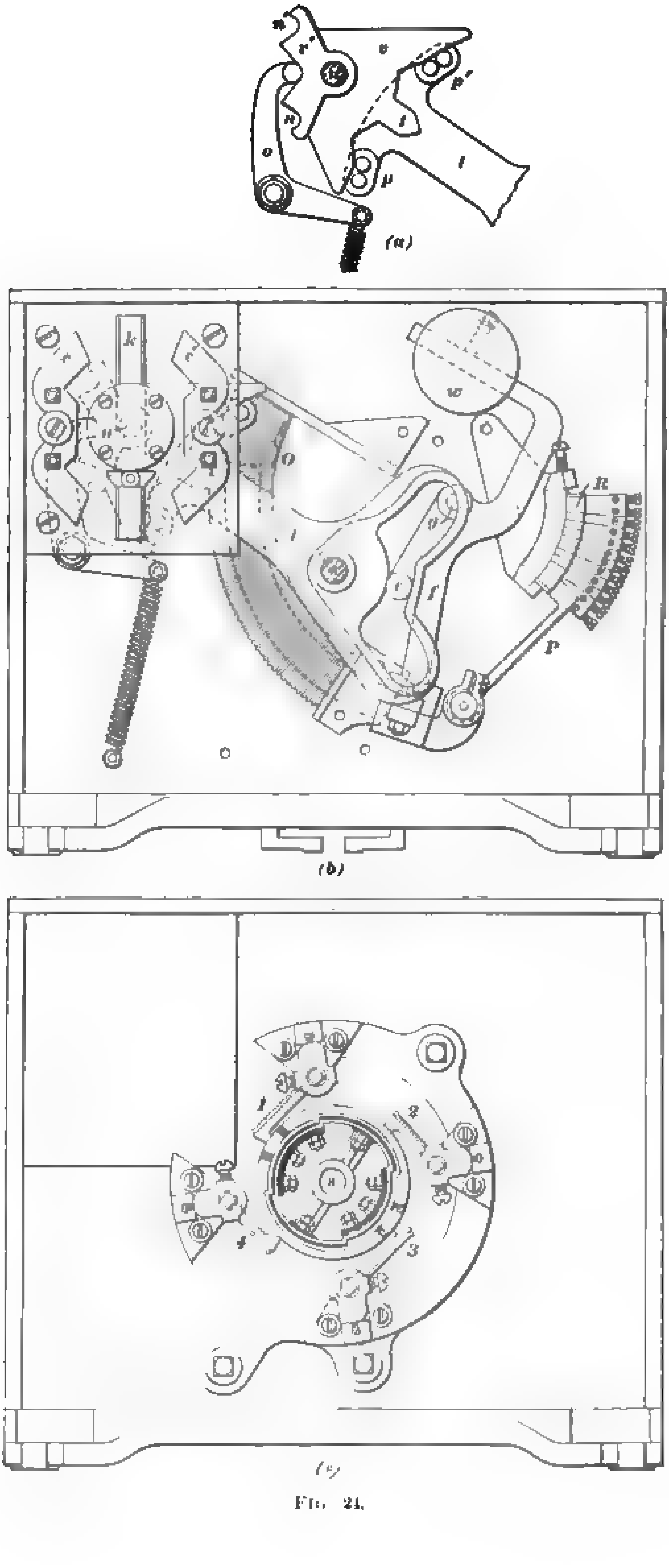


FIG. 23.

54. Controlling Devices.—The controller of the Otis elevators is box-shaped and is usually mounted on top of the motor, as shown at *C* in Figs. 21 and 22. It is operated by a rod *R* attached to the shipper sheave, which rod has an arm *A* on the other end, which engages by means of a part *a* with another arm or crank, hidden underneath the arm *A*; this crank is fastened to a shaft that reaches inside the controller box. In Fig. 24, which is a drawing showing the interior mechanism of the controller, this shaft is marked *s*. For clearness, the two parts (*b*) and (*c*) of the mechanism are



(a) (b) (c)

FIG. 24.

shown apart, while in reality part (*c*) is in front of part (*b*). Fig. 24 (*a*) is a detail view of some of the parts not very clearly shown in (*b*), where they are shown in dotted lines. The following is a description of the mechanism: the portion (*c*) contains the **reversing drum** mounted on and keyed to the shaft *s*; it has four contact plates insulated from one another. On these contact plates, of which two are long and two short, there rest four brushes *1*, *2*, *3*, and *4*, 90° apart. By turning the drum to the left, brushes *1*, *2* and *3*, *4* are made to rest on the same long contacts; while by turning the drum to the right, brushes *1*, *4* and *2*, *3* are brought into connection. The brushes are so connected to the armature and line that by turning the drum as aforesaid, the current in the armature is reversed. This will be plain from the diagram of connections given in Fig. 25. Behind the drum there is also fastened to the shaft *s* a lever *l*, Fig. 24 (*a*) and (*b*), carrying pins *p* and *p'*, which, when the shaft *s* is turned, engage a tooth *t* formed on a plate *v* pivoted at *u*. The plate *v* carries another plate *v'* having notches into which falls the end of a spring-actuated bell-crank lever *o*. By turning the shaft *s*, the plates *v* and *v'* are first turned around *u* until the end of the lever *o* rides on one of the sharp corners of the plate *v'*, whereby the spring of lever *o* is stretched. Turning the shaft *s* a little farther makes the end of the lever engage the inclined planes *n* or *n'*, which are so located that the spring causes the plate *v'* to make an additional quick rotary motion.

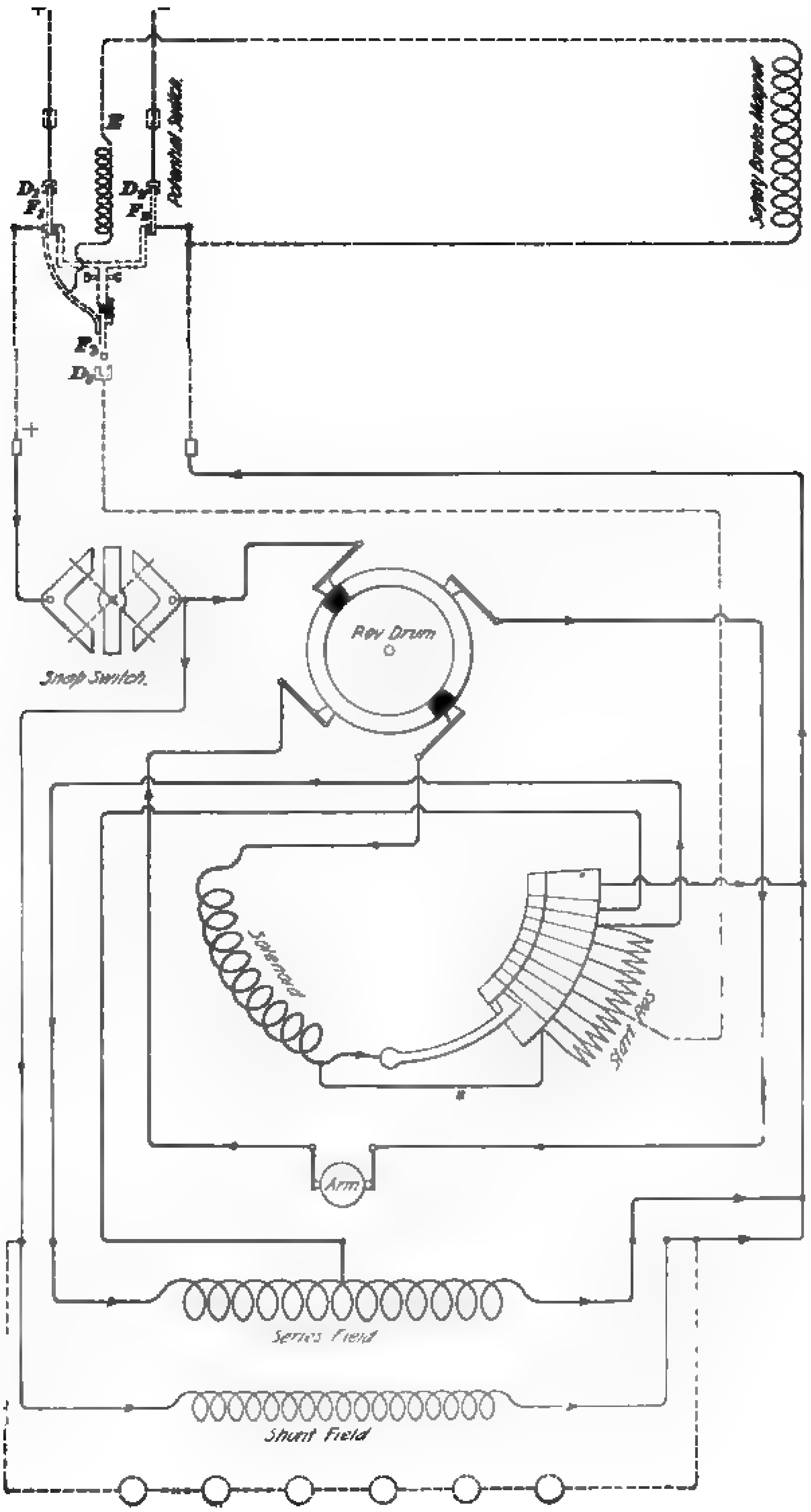
On the pivot *u* is fastened the blade *k* of the knife switch shown in the upper left-hand corner of Fig. 24 (*b*), and the quick rotary motion of the plate *v'* causes this blade *k* to snap between the clips *c* and *c'* of the switch. It is evident that on returning the mechanism to its middle position, the same snap action is caused by the two middle inclined planes of the plate *v'*, so that the switch blade *k* is quickly withdrawn from the clips *c*, *c'*, thus avoiding the formation of arcs; this is really the main object of the snap switch.

The other end of the lever *l* is formed into a cam of peculiar shape, which engages a pin *e* of a double-armed lever *f*

pivoted at *g*. This lever *l* has fastened to its lower end a curved magnet core entering a solenoid *O*, as well as a contact arm *P* arranged to slide over resistance contact blocks *R*. The greater part of the weight of the magnet core and arm *P* is counterbalanced by a weight *w* on the other arm of the lever *f*, so that when free to move, the magnet core, while having the tendency of swinging out of the solenoid, will be pulled back into the same as soon as the current will produce enough magnetism to overcome the unbalanced weight of the core and the arm *P*. The lever *f* becomes free to move, however, only after the shaft *s* has been turned enough to make the circuit at the snap switch, the cam on the lever *l* holding all parts in position until then.

55. Supposing that the solenoid and the resistance *R* are in series with the armature, it will be seen that the operation of this apparatus is as follows: First the circuits are closed with all the resistance in the armature circuit and the motor starts up. By the time the motor has gained some speed the lever *f* is set free, and if the speed of the motor is such that the counter-electromotive force is enough to cut down the armature current to the desired amount, the solenoid will not hold the core, the latter will swing out, and the arm *P* sliding over the contact blocks *R* will gradually cut out the starting resistance. Should for any reason the armature current increase above the normal, the solenoid will pull back the core, throwing resistance into the armature circuit. It is thus seen that the solenoid performs two functions: first, that of cutting out the starting resistance, and second, that of a safety device. In stopping, the lever *f* is brought back into the original position by means of the cam on the lever *l*, making the arrangement ready for starting again.

56. The diagram of connections given in Fig. 25 will be readily understood. It is to be noticed that the series windings of the field are cut out after all starting resistance is cut out. A safety wire *s* connects the end of the solenoid with the first resistance contact. This wire will keep the



Potential Switch
Safety Brake Magnet
Snap Switch
Rev Drum
Solenoid
Start Res
Arm
Series Field
Shunt Field

FIG. 26.

circuit closed even if, for some reason, the contact brush of the solenoid lever should fail to provide sufficient contact and thus stop the motor. The resistance coils are placed in a compartment of the controller box back of the mechanism shown in Fig. 24.

57. Brakes.—The brakes on the Otis elevators are of the band type. In the simpler forms, a steel band faced with leather encircles the pulley and is so connected to a weighted lever that the weight applies the brake. The lever is linked to the controller rod in such a manner that when the shipper sheave is turned either to the right or to the left the brake is released.

58. For high-speed service elevators, such as are shown in Fig. 22, a different kind of brake is used, for the reason that in such elevators the car must be stopped almost instantly without any possible slipping when the limits of travel are reached; while at any floor stop, midways of the travel, such instant stoppage is not so essential. The brake is, therefore, so arranged that it will be set in action by the limit stop much quicker and more effectively than by the ordinary device. The arrangement is shown in detail in Fig. 26.

On a stand *A* is a bearing *a* in which a short shaft *s* can revolve. To this shaft is keyed a crank-arm *C*, which in turn is connected by a rod *R* to the yoke of the limit-stop device *L*, Fig. 22. On the shaft *s* there is also keyed an eccentric *E* carrying another eccentric *E'*; the strap *D* encircling this outer eccentric is connected by a spring-cushioned rod *d* to the brake lever, and to it is also fastened the shipper sheave *S*, so that the latter, with the outer eccentric, turns upon the inner eccentric as a pivot. The outer eccentric has an arm *C'*, Fig. 26, connected to the controller crank by a rod *R'*, Fig. 22. To stop the car at intermediate landings, the brake is applied by turning the shipper sheave into the position shown in the figure, the outer eccentric pressing down on the brake lever. When, however, the limit stop is set in action, the inner eccentric

is turned, which, having a greater throw than the outer one, gives more pressure to the brake.

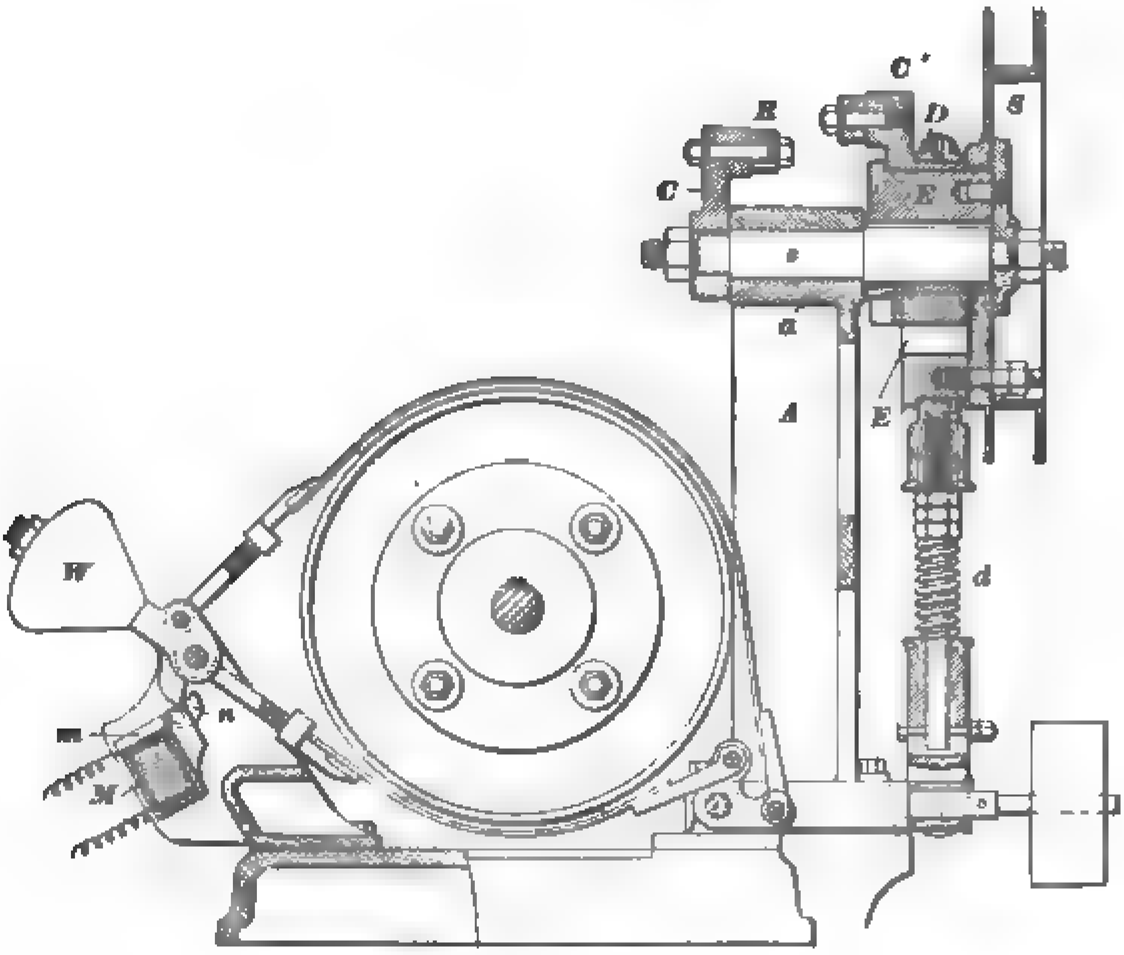


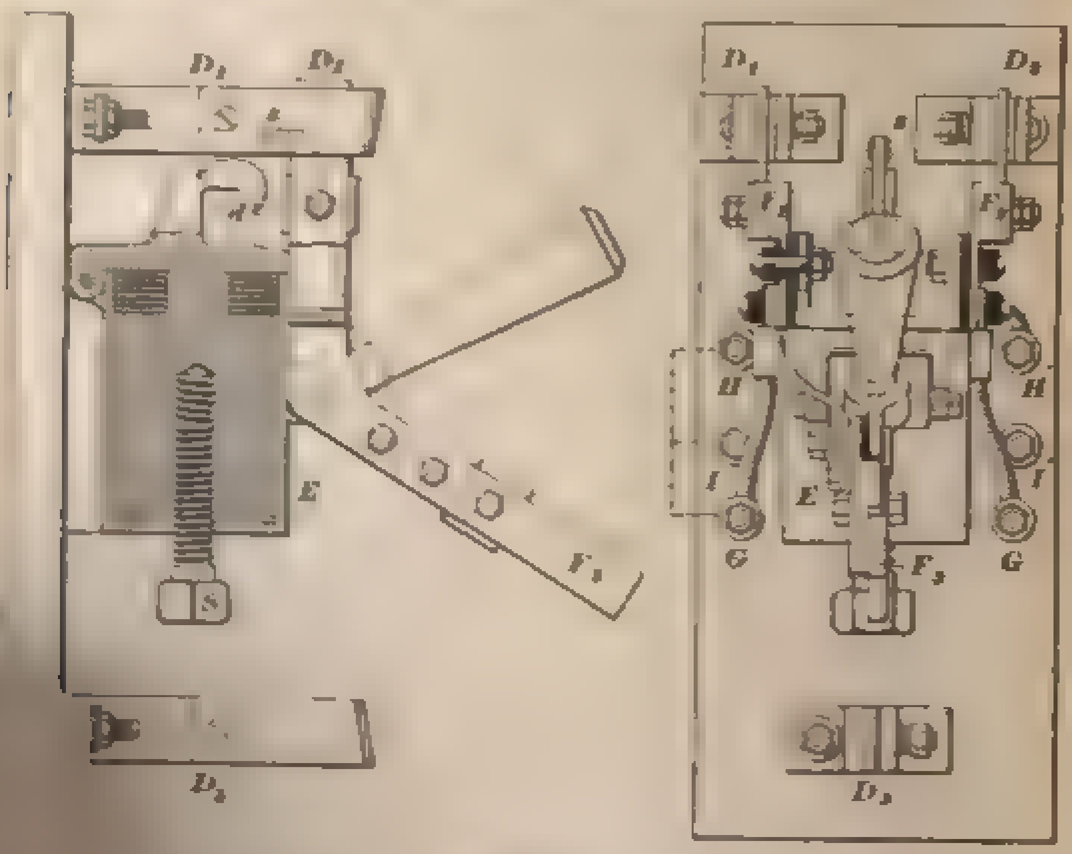
Fig. 26.

59. Another feature of the brake shown in Fig. 26 is the **safety magnet** *M*. This magnet serves to automatically apply the brake if the current should for any reason be interrupted in the system, and is placed in shunt with the motor, together with a so-called potential switch (of which we shall speak later), as shown in Fig. 25 in dotted lines. The armature *m* of this magnet has a projection, or nose, *n* which normally, that is, when a current of sufficient magnitude circulates through the magnet winding, holds in suspense a weight *W* connected to the free end of the brake band, as shown in Fig. 26. As soon as the current falls below the normal, the weight *W* trips the armature *m* and tightens the brake band. After the trouble [illegible] is safety arrangement to act has been remedied, [illegible]; is replaced into the position shown in Fig. 26

by operating the brake in the regular way. Dynamic braking is also resorted to.

60. Operating Devices.—For standard passenger and freight elevators, the simple hand rope is generally used; for high speed elevators, hand wheel devices or levers are preferred. To prevent accidental reversal of the motor in stopping, the tripping device (the lever l and the plate c) shown in Fig. 24 has considerable lost motion, or backlash.

61. Motor Safeties. Besides the safety magnet brake above described, the usual limit-stop arrangement, consisting of yoke and traveling nut, and a clutch operating the slack-cable safety, the Otis Company generally installs with the magnet brake a so-called **potential switch.** This switch, shown in detail in Fig. 27, has three blades F_1, F_2, F_3, with



[illegible] clips D_1, D_2, D_3, of which the [illegible] Fig. 25 to the line [illegible] to about the [illegible] the starting resistance. Blades F_1 and F_2 are

connected to the motor circuit as shown, and F_2 to F_1. An electromagnet E placed in the shunt across the line in series with the safety-brake magnet holds the blades F_1 and F_2 in contact with the clips D_1, D_2 by means of a catch c on the armature of the magnet engaging a projection d on the fulcrumed lever carrying the blades. A spring s counteracts the magnet and causes the blades F_1, F_2 to leave clips D_1, D_2 and the blade F_2 to engage the clip D_3 when the current in the magnet windings falls below the normal. This has the effect of breaking the main circuit, releasing the safety brake, and thereby short-circuiting the armature through more or less of the starting resistance, according to the position of the resistance arm at the time. This short-circuiting acts as a brake on the motor, as is well known.

62. The usefulness of the potential switch extends beyond the use just explained. In Fig. 28, a method of connecting up the potential switch is shown, by which the potential switch not only performs its function in case of a fall of electric potential, but also in case of an undue increase of current in the line. For this purpose the switch magnet E, Fig. 27, has two windings with opposite magnetizing effect. One winding (the one next to the armature of the magnet) terminates in the binding posts H, H', while the other terminates in binding posts I, I'. These posts are, respectively, connected so as to throw the magnet winding $H H'$ in series with the armature of the motor, and the coil $I I'$ in series with the safety magnet brake, as in the previous case.

The coils of the electromagnet are so proportioned that under normal conditions the shunt coil $I I'$ gives a stronger magnetic field than the series coil $H H'$, and since they are wound in opposition to each other, the shunt coil will thus normally hold the switch closed. But if the potential in the line falls below the normal, the switch will be opened, the magnet not holding against the spring. Again, if the current in the armature circuit rises above the normal, the series coil of the magnet will produce a stronger field than normally, with the effect of weakening the field produced by

the shunt coil, so that eventually the magnet will be demagnetized enough to let go of the switch lever. It is thus seen that the switch operates not only under a fall of potential

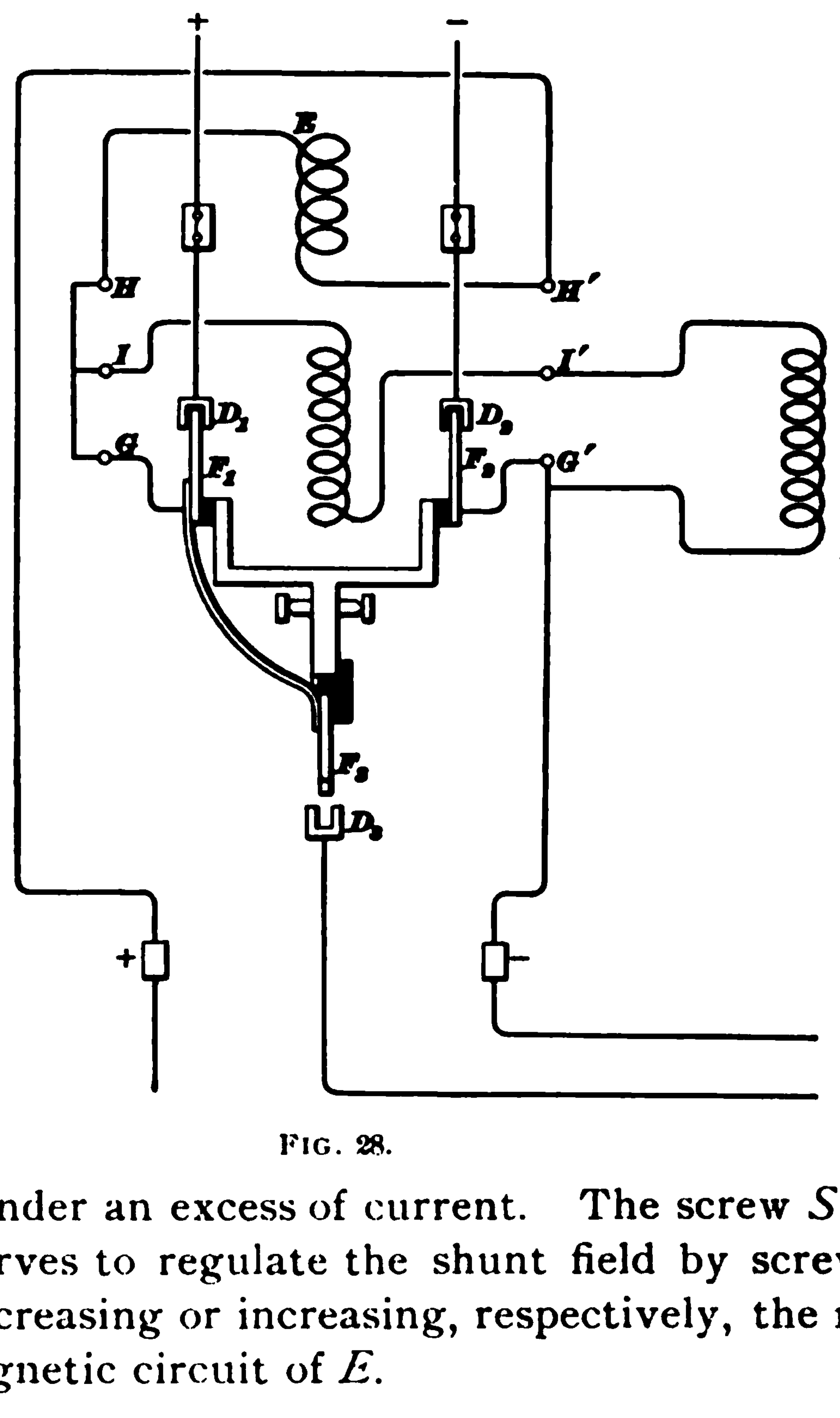


FIG. 28.

but also under an excess of current. The screw S shown in Fig. 27 serves to regulate the shunt field by screwing it in or out, decreasing or increasing, respectively, the resistance of the magnetic circuit of E.

ELEVATORS OPERATED BY ALTERNATING CURRENT.

63. While direct current is preferable for the operation of electric elevators, in many cases alternating current is the only source of power that is available. Two-phase or three-phase alternating current is generally used for elevator operation. Prior to the introduction of the two-phase

and three-phase systems, alternating current was very little used for motive purposes because the single-phase alternating current motor would not start of its own accord under load; on the other hand, two-phase and three-phase motors give a good starting torque and will run up to speed in much the same way as a direct-current motor. An alternating-current induction motor consists of two main parts: the primary, or stator, which is the stationary part, and the secondary, or rotor, which is the revolving part.

The primary consists of a laminated body provided around its inner circumference with slots in which the primary coils are placed. These coils are connected together, and the terminals connect to the line when the motor is in operation. The secondary, or rotor, is also a laminated body provided with slots around its circumference in much the same way as a direct-current armature. In many induction motors, each of these slots contains a heavy copper bar, which is connected to a copper ring at each end of the armature, thus forming what is known as a squirrel-cage winding. In other types of machines, especially those that must give a good starting effort and are started and stopped frequently, the armature is provided with a three-phase winding and the three terminals brought out to collector rings mounted on the armature shaft. This is done so that resistance may be inserted in series with the armature windings when the motor is being started, and thus allow a good starting effort to be obtained without an excessive rush of current. In some cases resistance is inserted in series with the field, or stator, at starting instead of in series with the armature. This avoids the use of collector rings, but it does not give as good a starting effort for a given current as when the resistance is used in series with the armature. The student should note particularly that in the alternating-current induction motor no current is led into the armature from the line; in fact, there is no connection between the armature and the line. The armature currents are set up by the inductive action of the constantly shifting magnetic field that is set up by the two-phase or three-phase currents in the

stationary field winding. This point should be borne in mind, as it will aid in understanding the connections to be described later.

OTIS ELECTRIC ELEVATOR WITH ALTERNATING-CURRENT MOTOR.

64. General Description.—Fig. 29 shows an Otis elevator operated by a three-phase induction motor *A*. This motor is of the type manufactured by the General Electric Company and is arranged so that a resistance is inserted in series with the armature windings at starting. In order to allow the insertion of this resistance, the armature is provided with three collector rings, shown at *b*, contact being made with the rings by means of carbon brushes The motor operates the drum by means of a worm-gear, as already described in connection with other elevators. The starting, stopping, and reversing are controlled by a shipper sheave *S* operated from the car. When the shipper sheave is moved in either direction, a cam moves the rod *r* back and forth. In the figure the shipper sheave is in the neutral position. *R* is the reversing switch that connects the motor to the line and controls the direction of rotation of the motor. This switch is operated by the cam *c*. The shaft *s* of the switch carries a number of arms, which engage with suitable contacts when the switch is moved to either the up or down position. The cam *c* has three prongs that engage with prongs on a segmental gear *G*, and when the car reaches the limit of its travel in either direction, the traveling nut on the drum shaft causes *G* to open the circuit and stop the motion of the car In the position shown in the figure, switch *R* is open; when thrown to the right, it makes connections for the car to go up, and when thrown to the left, it reverses the motor Enough backlash is given between the prongs of the cam *c* and the lugs on the wheel *G* to insure safety against overthrowing the switch. When switch *R* is operated, the motor starts up with all the resistance in the armature circuit and means must be provided for

cutting out this resistance as the motor comes up to speed. This is accomplished by the controller shown at O.

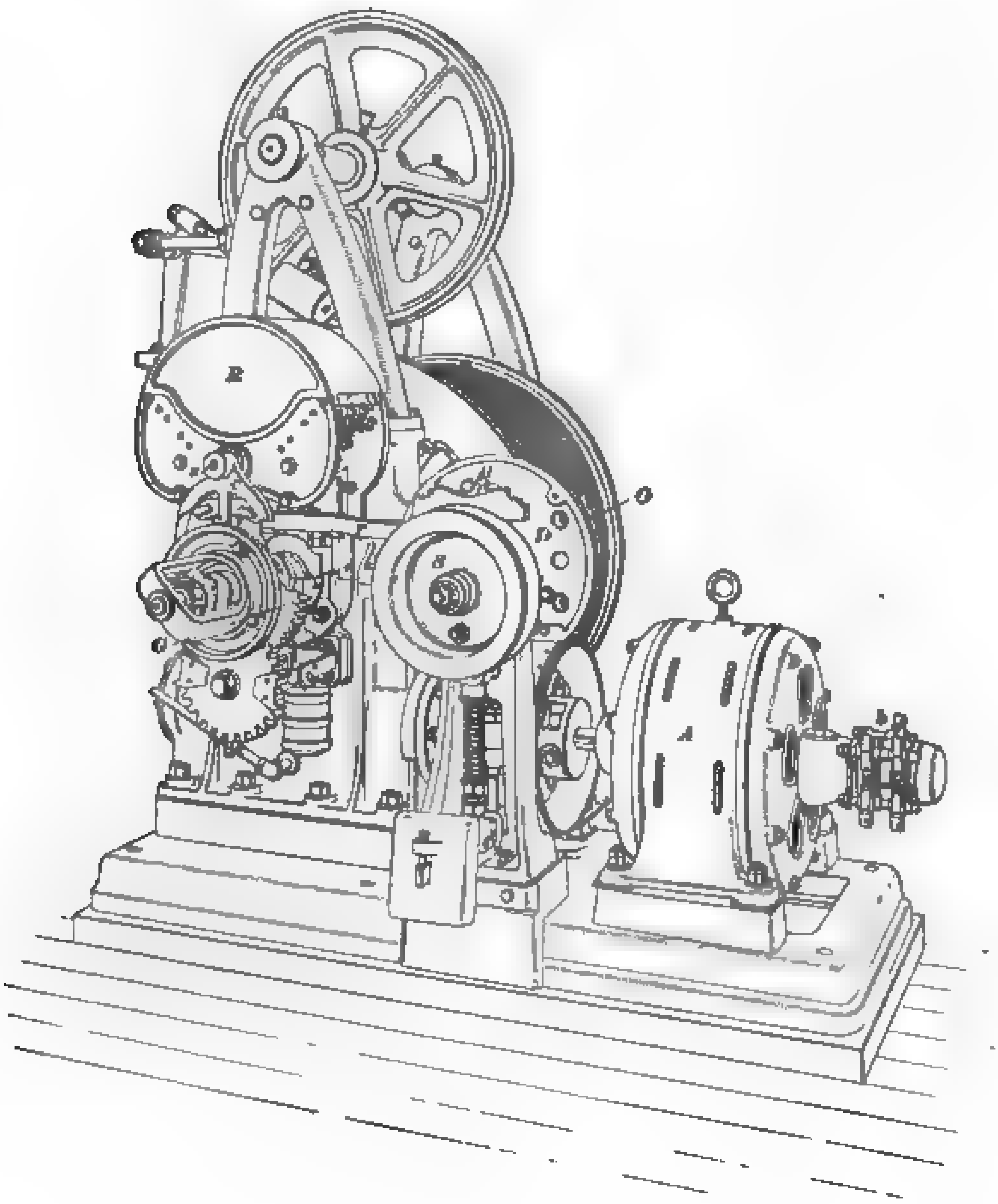


FIG. 29.

65. The Controller.—The controller is operated by means of the rod r, which raises the roller g whenever r is moved. The roller g is mounted on the end of a lever, as indicated in Fig. 30 (b). Fig. 30 (a) shows a rear view of the controller. D is the supporting cast-iron plate that carries the slate pieces S, on which are mounted a number of

contacts l_1, l_1, l_2, l_2, etc. The hinged fingers f_1, f_1, f_2, f_2, etc. also carry contact pieces, and in the position shown in the figure, the fingers are in connection with their respective contacts mounted on *S*. When they are in this position, all the resistance is cut out and the motor runs at full speed, as will be shown later. As soon as *r*, Fig. 29, is moved, roller *g* is raised and casting *E*, Fig. 30 (*a*), is forced down, thus compressing the spring *F* and raising all the fingers. At the same time, the reversing switch is closed and the motor

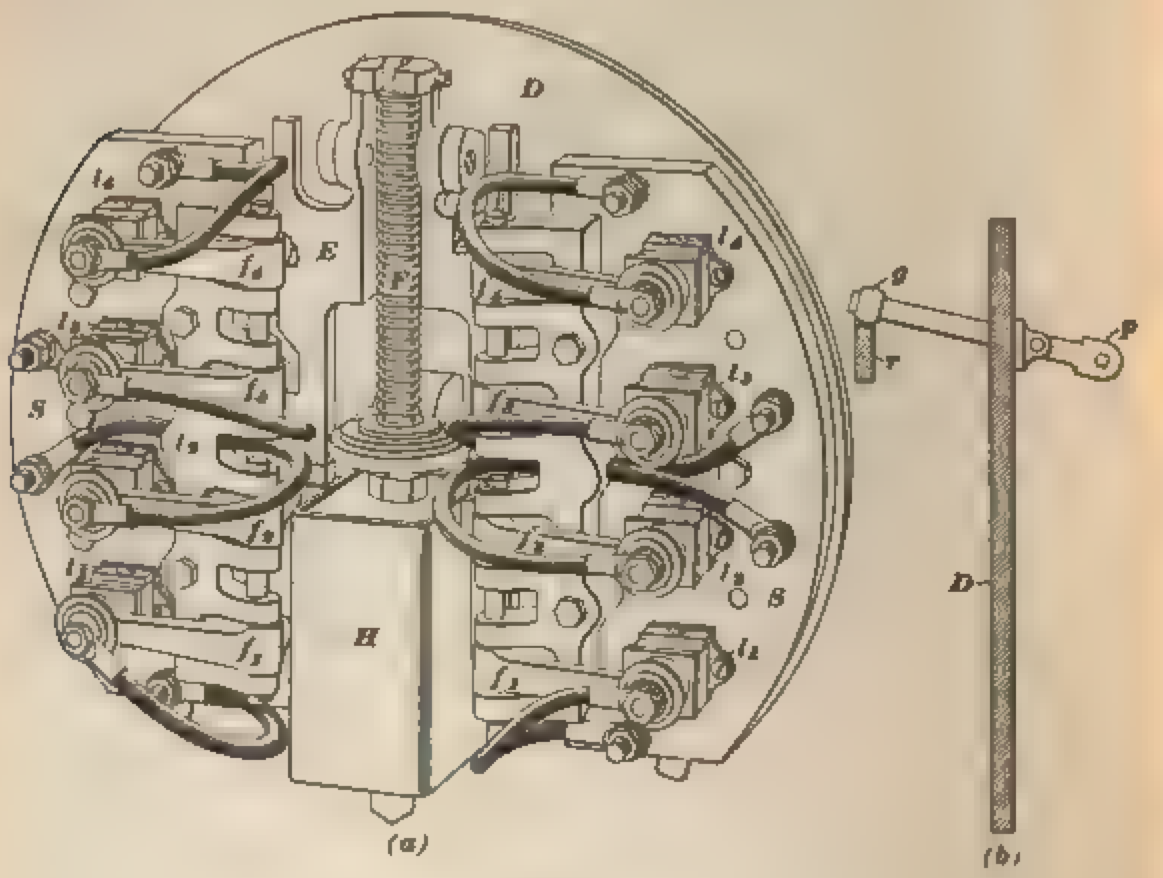


FIG. 30.

starts up with the resistance in. When roller *g* rides over the cam on *r*, the spring *F* forces up *E*, the upward motion being gradual because of the dashpot *H*. Casting *E* is provided with a number of cams, or notches, so placed that as *E* rises, the fingers *f* are closed down in pairs; i. e., the two lowest fingers first make connection with their contacts, then the next pair, and so on until all the contacts are closed, as shown in the figure. The closing of each of the pairs cuts out a section of resistance in each of two of the motor windings.

66. Connections and Operation.—The operation of the reversing switch and controller will be understood by referring to Fig. 31, which gives the electrical connections. R is the reversing switch and M the main switch, which is operated by hand and is only used when the motor is to be cut off entirely from the line. Switch R is provided with six clips *4*, *5*, *6*, *4'*, *5'*, *6'*, which engage with the blades or

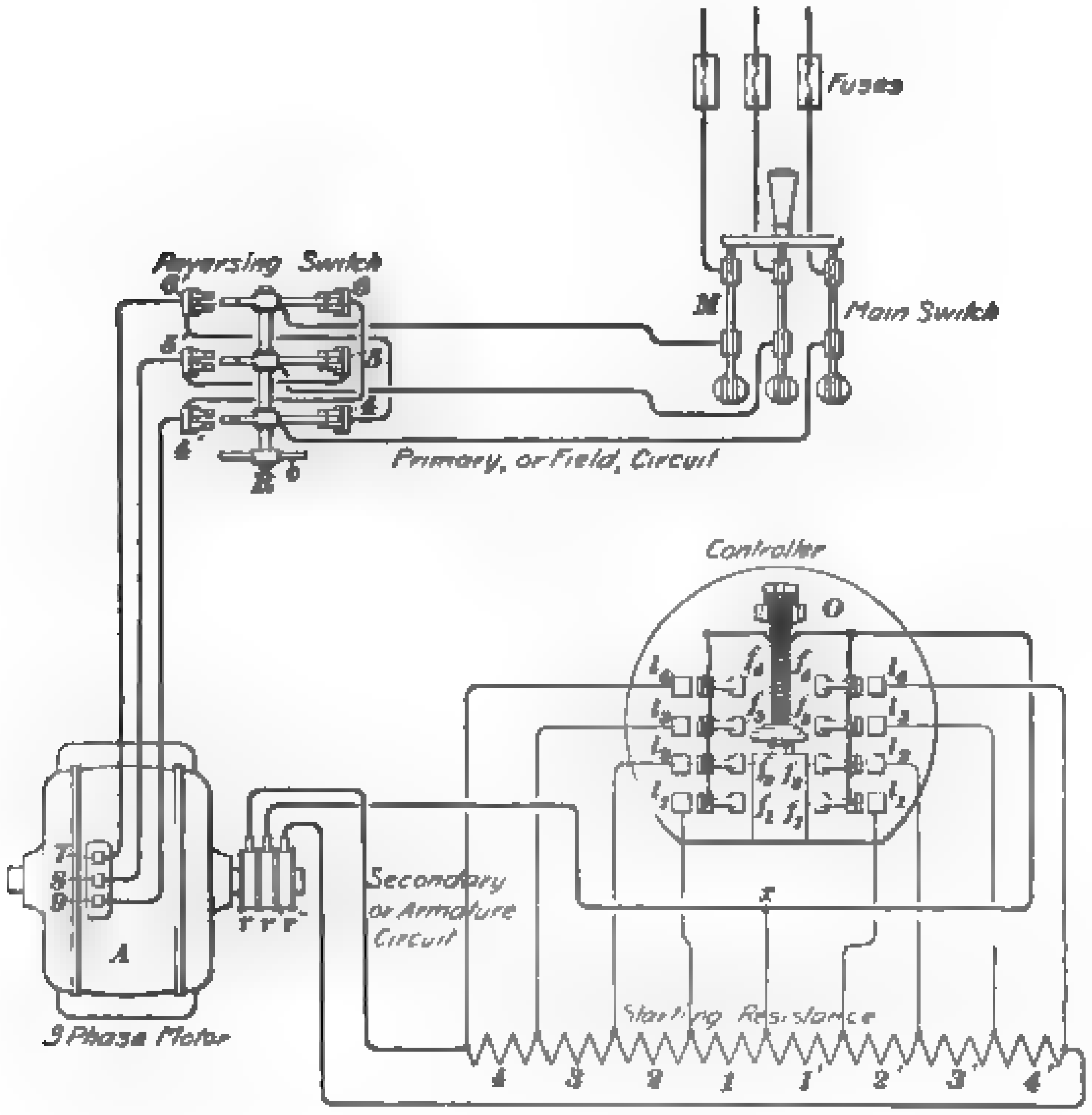


FIG. 31.

contact arms mounted on the shaft of the switch when the shaft is rocked by means of the cam *c*. In the position shown, the switch arms engage the right-hand clips and connection with the left-hand row is broken. The field terminals of the motor are *7*, *8*, *9*; and it is easily seen that when R is thrown over, the connections of *7* and *9* to the

line are interchanged, thus reversing the motor. There is no resistance in this primary circuit, and the secondary or armature circuit in which the controller O is placed is entirely separate from the primary. In the position shown, all the fingers f_1, f_2, etc. are raised off the contacts l_1, l_2, this being the position they occupy at the moment of starting. The induced armature current in flowing from ring r' to r must take the path r'-a-*1*-*2*-*3*-*4*-r, thus passing through four sections of resistance. Also, in flowing from r' to r'' it must pass through the four resistance sections *1'*, *2'*, *3'*, *4'*. The insertion of this resistance in the armature windings keeps down the rush of current through the primary and results in a good starting effort. As the casting E, Fig. 30 (a), rises, fingers f_1 and contacts l_1 make connection, thus short-circuiting sections *1* and *1'* of the resistance. As E rises still farther, sections *2* and *2'* are cut out by f_2 and l_2 making contact, and so on, until all the fingers are down and all the resistance cut out. In passing from ring r' to r, the current now takes the path r'-f_1-l_1-r and there is no resistance in circuit. When, therefore, the fingers are all down, rings r, r', and r'' are connected together and the induced armature currents are provided with a closed circuit in which there is no resistance other than that of the copper armature conductors and the connecting wires.

67. The number of steps of resistance depends on the service to which the elevator is to be put. For example, some controllers are provided with only three sets of contact fingers, as it is found that three sections of resistance are sufficient to give a smooth start. The connections for a two-phase motor are practically the same as those shown, so that it is not necessary to describe them in detail.

ELECTRIC ELEVATORS WITH MAGNET CONTROL.

68. General Features of Magnet Control.—In most of the controlling devices so far described for electric elevators, the cutting out of the starting resistance is accomplished by means of an arm carrying a contact that slides over a

series of plates, or contacts, connected to the sections of the resistance. This method works very well if the contact brush and contact plates are kept in good condition, but if either of them become rough or burned, the starting rheostat rapidly gets into very bad shape on account of the poor contact and consequent burning action. This is especially the case if the motor requires a large current for its operation, because the larger the current, the more perfect must be the connections made by the rheostat contacts, and a contact that is at all defective will very soon give rise to burning and cutting.

69. In order to avoid the use of a sliding contact with its accompanying contact plates, the so-called magnet system of control has been devised, in which the resistance is cut out by a series of electromagnetic switches, each one of which operates independently and which is so designed that it will handle a large current with very little burning or arcing. As these switches are simply of the make-and-break variety and have no sliding contacts, any small amount of burning that may take place does not interfere with the operation of the controlling outfit. There are many ways in which the system of magnet control may be applied. The electromagnetic switches may be arranged to operate automatically as the motor increases in speed; they may be controlled entirely by a controlling switch on the car, or part of them may be controlled automatically and part from the car. These resistance-controlling switches, together with the other electromagnetic switches necessary for closing the main circuit and reversing the armature connections, are mounted on a switchboard, which is usually separate from the elevator motor and hoisting mechanism.

70. Elementary System of Magnet Control.—Before taking up an elevator with magnet control, we shall consider the elementary arrangement shown in Fig. 32. This diagram is intended merely to illustrate the principle and does not represent any special controller. It shows an ordinary shunt motor *M* with its starting resistance *R* controlled

by the two magnets S, S'. The starting and reversing switch is shown at A, and in this case it is supposed to be operated by hand. Of course, if the motor were used in connection with an elevator, switch A could be operated from the shipper sheave. When the switch is in the position shown, the motor runs in one direction, and when it is thrown over so that the blades occupy the position shown by the dotted lines, the motor is reversed. The starting resistance is divided into two sections a, b, which are successively

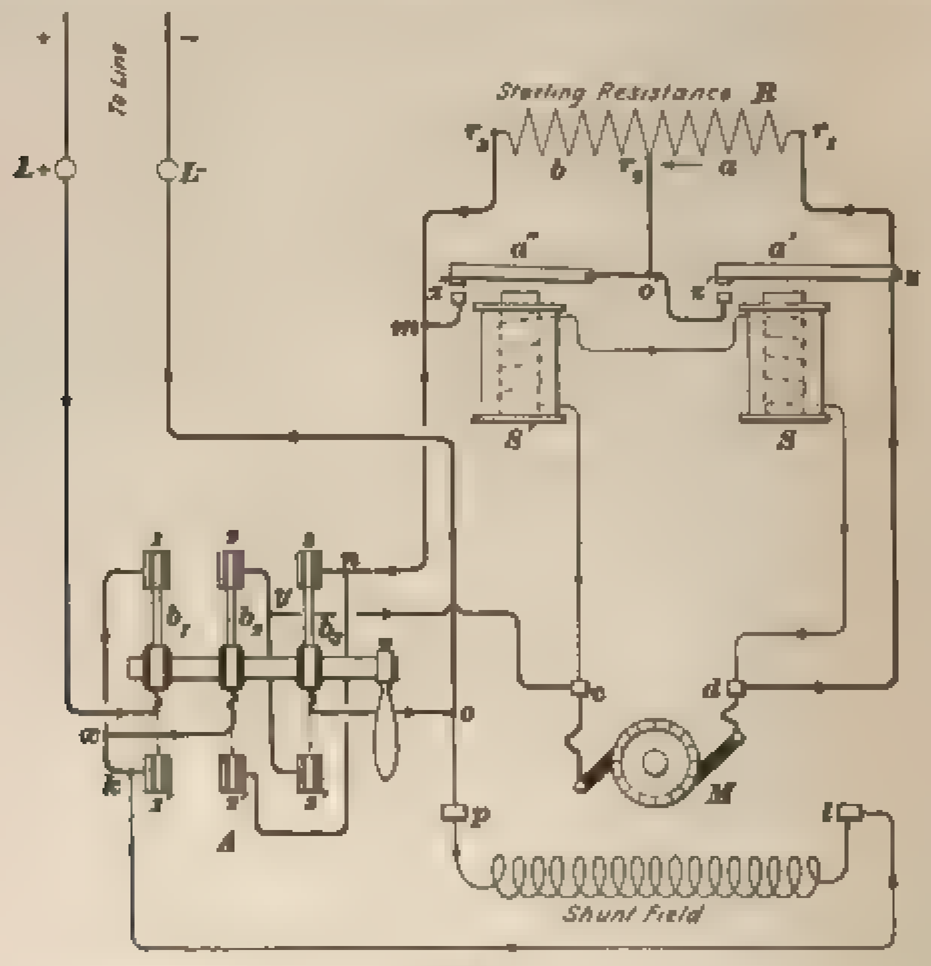


FIG. 32.

short-circuited by the electromagnetic switches S, S' when the motor comes up to speed. The windings of S, S' are connected in series across the armature terminals, forming a shunt circuit to the armature. When the main switch is closed, all the resistance is in series and the pressure across the armature terminals and coils S, S' is very small; consequently, very little current flows through S, S'. However, as the motor speeds up, its E. M. F. increases and

the pressure across the brushes increases, and this increases the current through S, S'. The armatures of these switches are so adjusted that S will operate with a smaller current than S'; consequently, as M comes up to speed, S closes and cuts out section a of the resistance by short-circuiting it. As the speed increases still further, the current through S and S' becomes strong enough to operate S', and section b is short-circuited, thus connecting the motor armature directly to the line. Suppose that the motor is to be started and that switches A, S, and S' are in the positions shown. The path of the current through the shunt field is as follows: $L+-b_1-1-k-l-$ through shunt field$-p-o-L$. The path of the main current through the armature and starting resistance is $L+-b_1-1-x-b_2-2-y-c-$ through armature of motor$-d-z-r_1-r_2-3-b_2-o-L$. When the current through the shunt-magnet circuit $C-S'-S-d$ has become strong enough to pull down armature a', contact is made at z' and the main current on reaching z takes the path $z-a'-z'-o'-r_2-r_3-3-b_2-o-L$, thus flowing past section a of the resistance that is short-circuited. When S' operates, the current takes the path $z-a'-z'-o'-a''-z''$, and so on, the whole of the resistance being thus short-circuited. Any arcing, or burning, that may occur will take place at contacts z' and z'', and this can easily be taken care of by providing suitable contacts. Moreover, it will be noticed that the closing of an armature short-circuits the resistance, and that when an armature opens, the circuit is not broken, because the current still has the alternative path through the resistance. The result is that when the armature leaves its contacts there is but little sparking.

71. When the motor is to be run in the reverse direction, switch A is thrown over to the position indicated by the dotted lines. This does not change the direction of the current through the shunt field, but it reverses the current through the armature, the path being as follows: $L+-b_1-1'-x-b_2-2'-n-r_2-r_1-d-c-y-3'-b_2-o-L$. Since the current through the armature is reversed while that in the field remains the same, the direction of motion is reversed.

The scheme of using electromagnetic switches to control the starting resistance has been embodied in the controllers of a number of different manufacturers. It has been found that it is not necessary to provide a great many resistance sections and resistance-controlling switches in order to give a smooth start. The actual number needed depends, of course, on the conditions under which the motor is operated. With an ordinary sliding-contact rheostat, it is necessary to provide quite a large number of resistance sections, in order to keep the voltage between adjacent contact plates down to the small amount necessary to avoid sparking when the arm slides from plate to plate. With electromagnetic switches the number of sections can be much smaller, because this precaution is not necessary. Moreover, when the cutting out of resistance is controlled by switches that are in turn controlled by the counter E. M. F. of the motor, the resistance is never cut out until the armature has come up to such a speed that it is able to take care of the increased current. The resistance is, therefore, cut out just when the armature is ready for it and not before; such being the case, fewer resistance sections are necessary than if the cutting out were controlled by hand.

72. With most high-speed passenger elevators using this method, the switches that perform the same duties as *A*, Fig. 32, are operated by electromagnets or solenoids, thus doing away with the shipper sheave with its cable, cams, and other switch-operating devices and replacing them by an electric cable connecting the car-operating switch to the switchboard.

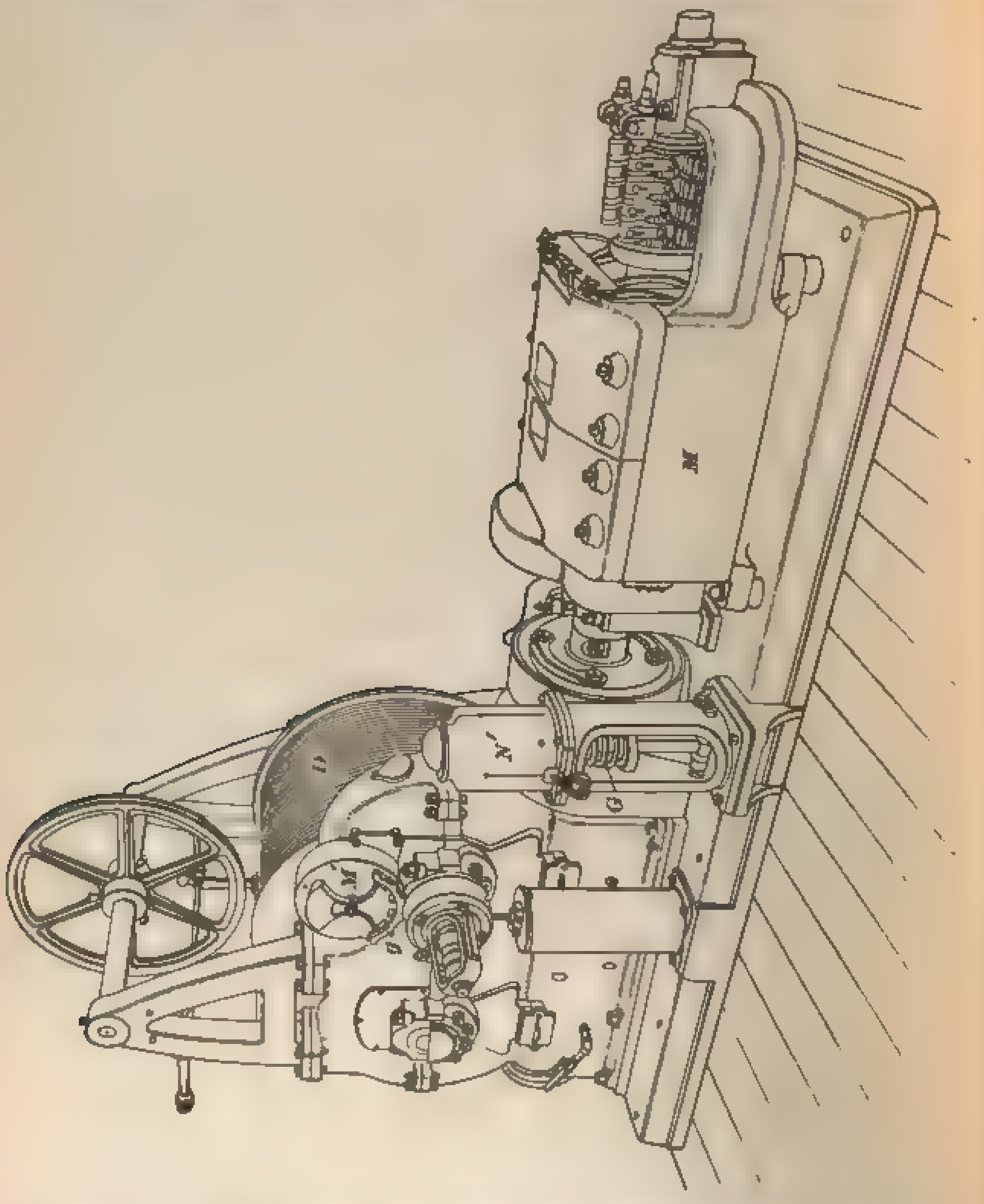
73. The car-operating switch replaces the ordinary operating wheel or lever used for operating by means of a cable. The cable running from the operating switch to the switchboard carries the wires that connect to the electromagnetic switches, and as these switches require only about ¾ ampere for their operation, the wires in the controlling cable do not need to be large. This method of control is

being used quite largely for various kinds of service, and, as pointed out above, it has advantages over the older sliding-arm method of controlling resistance. In order to illustrate its application in practice, we will describe two controllers made by the Otis Elevator Company and covered by patents owned by them.

OTIS ELEVATOR WITH G. S. MAGNET CONTROLLER.

74. General Description of Elevator Machine.—Fig. 33 shows a direct-connected Otis electric elevator for use with magnet control. The motor *M* operates the drum *D* by means of double worm-gears. This particular machine is provided with back gearing between the motor shaft and worm-shaft, so that unusually heavy weights, such as safes, may be lifted. It will be noticed that there is no electric controller connected to the machine other than the brake magnet *N'* and the stop-motion switch *M'*. The brake magnet is a powerful solenoid that operates against the spring *G*, so that when the magnet is energized the band brake is released, and when current ceases to flow through the magnet, the brake at once goes on. The stop-motion switch *M'* will be described more in detail when the electrical connections are taken up. Its function is to cut off the current and stop the motor whenever the car approaches the limit of its travel in either direction. Under ordinary running conditions, the intermittent gear *g* remains in the central position shown in the figure. When the car approaches the limit of its travel, the safety nut on the shaft of the worm-gear causes a pin to engage with *g*, thus making it swing over. This operates a switch arm inside the casing *M'*, which breaks electrical connections and slows down the motor. When the safety nut makes another revolution, *g* is swung over another notch and the motor is stopped completely. The mechanical features of the hoisting machine are similar to those that have already been described and do not call for special attention.

75. General Description of Otis G. S. Magnet Controller.—Fig. 34 is a general view of the Otis G. S. magnet controller. The controlling devices are mounted on a heavy



slate panel *A*, which is in this case supported on an iron framework *B* that also serves to house the resistance coils. With many controllers, the resistance is placed in a case

arranged behind the switchboard. The various electromagnetic switches necessary for controlling the direction of motion of the car and the cutting out of the starting resistance are mounted on *A*.

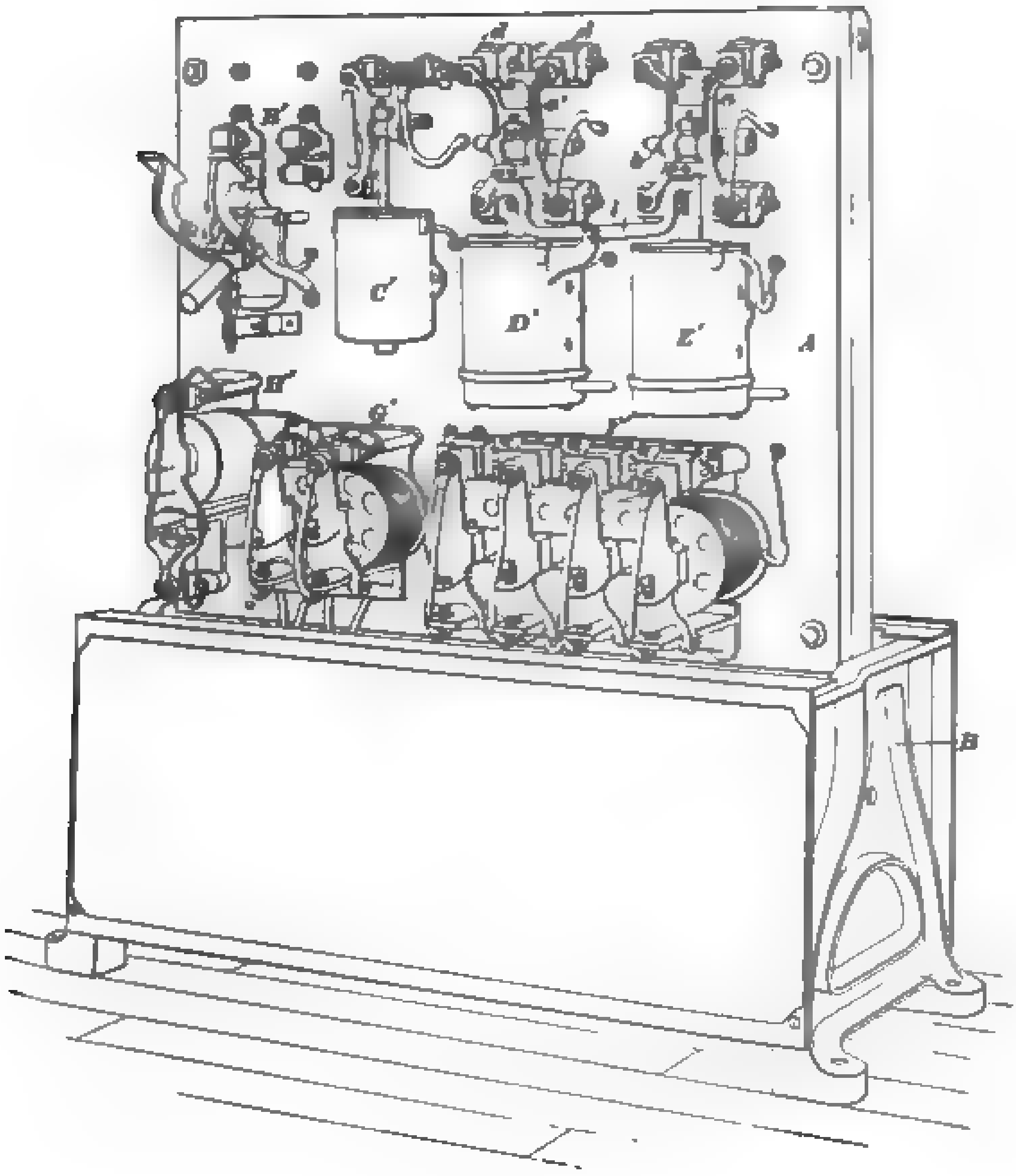


FIG. 34.

In Fig. 34, *B'* is the potential switch, the use of which has already been explained. It is a protective device and is not concerned with the regular starting and stopping of the elevator. When the elevator is in operation it remains closed. Switches *C'*, *D'*, and *E'* control the main current.

Switch H' controls the brake and the two groups of switches G' and F' control the resistance. The group of four switches F' controls the starting resistance and the pair of switches G' controls the stopping resistance. With these controllers the motor is stopped by allowing it to act as a generator, thus providing a dynamic-braking action in addition to that of the band brake. In order to allow a smooth braking action, the current generated by the motor is passed through a resistance, and this resistance is cut out or in by magnets G'. The main operating magnets C', D', and E' are of the solenoid type, and when they are not excited the plungers are down and the upper switch contacts, as c, for example, are separated from the fixed contacts d. The movable contacts c are mounted on rocker-arms a, a' pivoted as shown at b. The plungers of the two switches D' and E' are connected by a lever l, as shown, so that when one contact lever a is up, i. e., the upper terminals in contact, the other lever a' is down, and it is impossible for both levers to occupy the up or down position at the same time. The operation of these switches will be understood more clearly by referring to Fig. 35 (a). Switches F' and G' are arranged as shown in (b) and switch H' is as shown in (c). These sketches are intended merely to indicate the operation of the switches, so that the diagram of connections to be given later may be readily understood; hence, particular attention has not been paid to the mechanical details. In (a), when the magnet draws [illegible] is moved so that c and d make contact, [illegible] d are, of course, opened. Con[illegible] blocks mounted on spring holders, [illegible] plate being to prevent damage from [illegible], and especially to obviate the danger of [illegible] sticking, together as might possibly [illegible] copper. Fig. 35 (b) shows the con[illegible] resistance-controlling switches; [illegible] which [illegible] embrac[illegible] G [illegible]

series of cores *h*, opposite each of which is hinged the armature *a* carrying an insulated contact *c*, which makes contact with *d* when the armature is drawn down. When current flows around coil *f*, all the cores are magnetized to about the same degree, but the armatures are not all attracted because they are adjusted to different distances from the pole pieces *s* by means of adjusting screws *p* that rest against lugs *r*. The armature with the shortest air gap between *a* and *s* is first attracted, then the next, and so on, the armatures closing in succession as the magnet increases in strength on account of the motor speeding up. The resistance is thus automatically cut out by steps, as explained in connection with Fig. 32.

Fig. 35 (*c*) shows the switch indicated by *H'* in Fig. 34. It is practically the same as (*b*), except that it is provided

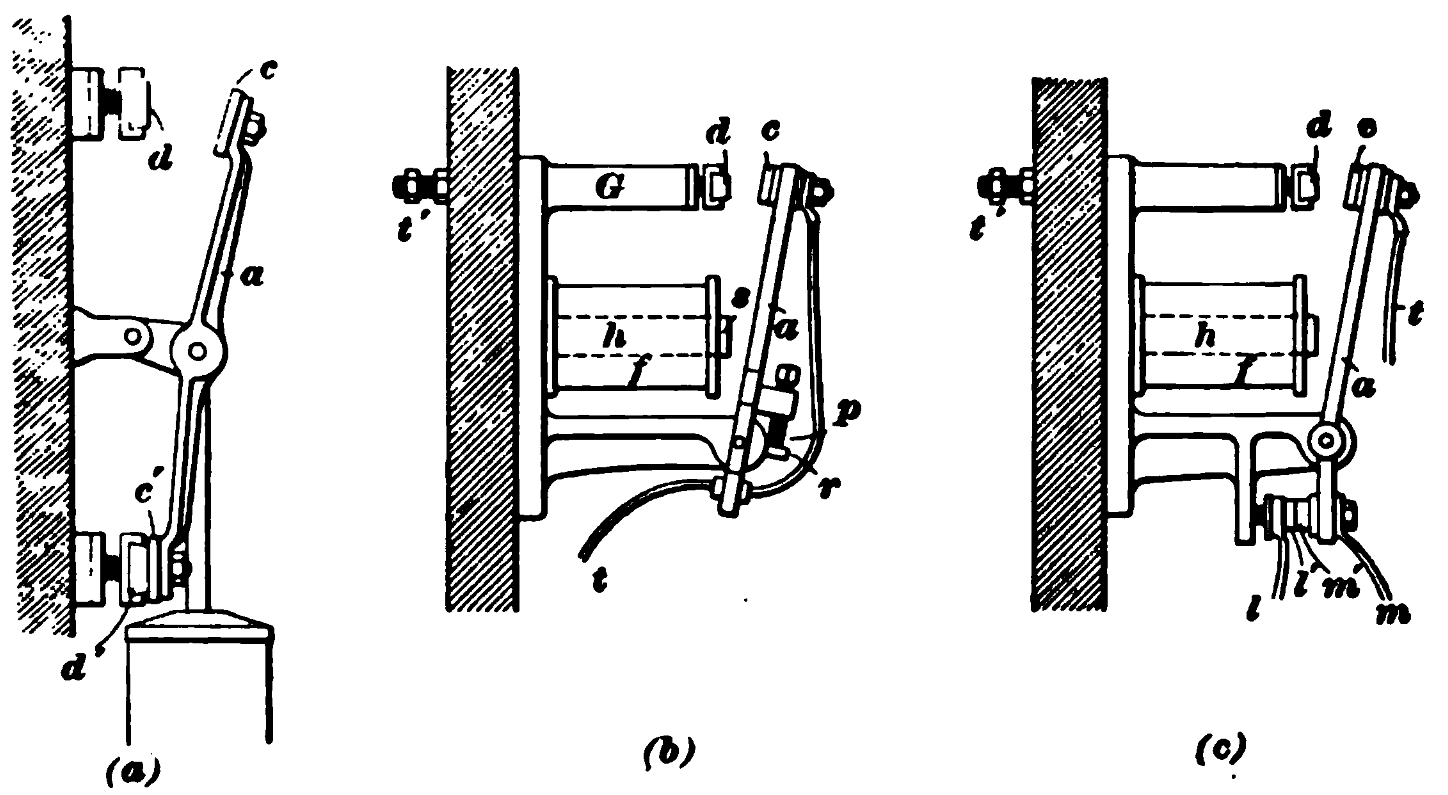


FIG. 35.

with two insulated back contacts *l'*, *m'* to which the leads *l m* are connected. When armature *a* is unattracted, *l'* and *m'* are in contact; when *a* is attracted, contact between *l'* and *m'* is broken and contact between *c* and *d* is closed. The switch contacts that are most liable to arcing are provided with magnetic blow-out coils. These are coils provided with an iron core so placed that a magnetic field is set up between the contacts, and as soon as the arc forms, it is forced across the field and broken almost instantaneously.

76. Car-Operating Switch. Fig. 36 shows the style of car operating switch used with the magnet controller. When the motor is stopped, the handle occupies the vertical position and is thrown to the left or right, according as the car is to go up or down. When the cover is closed and the switch in use, sliding contacts c, c bear against the arcs a, a, b, b; when the switch is off, they bear against the insulating pieces d, d. The contacts on the back of the operating lever press against segments e, thus making the required connection. By adopting the construction shown, no current flows through the hinge f. The exact arrangement of the contact segments varies with different controllers, as the starting and running requirements are not always the same for different installations. The operating switch for which the connections are shown in Fig. 38 is somewhat simpler than that shown in Fig. 36, and requires fewer wires and contact arcs, but its general construction is the same.

Fig. 36.

77. Stop-Motion Switch.—Fig. 37 shows two views of the stop motion switch shown at M, Fig. 33. The use of this switch has already been explained, but Fig. 37 shows the construction

and will aid in understanding the electrical connections. The arm *a*, which is operated by the intermittent segmental gear *g*, normally occupies the horizontal position, but is swung around whenever the car reaches the limit of its travel. Contact brushes are mounted on the arm, and these rub on the contact arcs *b*, *b*. When the arm is swung

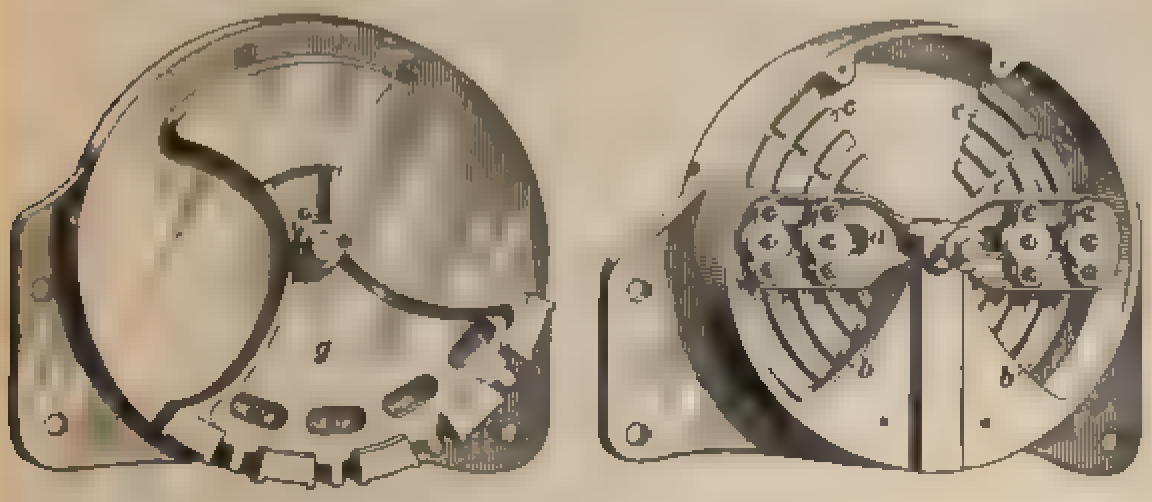


FIG. 37

around in either direction, one set of brushes leaves the long contacts *b*, *b* and passes on to the short pieces *c*, *c*. Arcs *c*, *c* are, with the controller to be described, not connected to anything, but serve as bearing pieces; as soon, therefore, as the contact arm slides on to them, electrical connections are broken, which causes the motor to stop.

78. Connections for G. S. Controller.—Fig. 38 shows the general scheme of connections for the G. S. controller. In order to simplify the diagram, the relative positions of a few of the parts have been changed; for example, the starting resistance and the extra-field resistance *r r'* are shown connected directly to their switch contacts. The relation of the various switches is the same as shown in Fig. 34, except that their order is reversed, because all the connections are made on the back of the board; corresponding switches in Figs. 34 and 38 are lettered alike. In order to facilitate the tracing out of connections, all *fixed* contact pieces on the switches have been shaded, while all *movable* pieces have been left open. For example, on switch *k'* the shaded contact pieces *5'*, *6'*, *7'*, and *8'* are mounted on the slate panel

and the open contacts *5*, *6*, *7*, and *8* are mounted on the tilting arm shown in Fig. 35 (*a*). Also, contacts that touch each other are marked with similar figures, i. e., when switch E' is pushed up, *5* makes contact with *5'* and *6* with *6'*. A few details, such as blow-out coils, have been omitted, as they are not necessary to illustrate the operation of the controller. The car-operating switch controls switches E', D', C', and H'; switches M', F', and G' operate automatically. The main switches E' and D' are each provided with two coils. One of these coils is of fine wire, and the current in it is controlled by the car-operating switch. The lower coils are of coarse wire, and carry the main motor current; these coils are arranged below the fine-wire coils and, when energized, hold the switch down. When switch C' operates, *13* makes contact with *13'*, *14* with *14'*, and contact between *15* and *15'* is broken. When H' operates, contact is made between *16* and *16'* and broken between *17* and *17'*. When switches G' and F' operate, contact is made between *1* and *1'*, *2* and *2'*, etc. The movable contact pieces of the stop-motion switch M' occupy the horizontal position shown until the car reaches the limit of its travel in either direction. The full-black segments on this switch are not connected to anything, being in this case bearing surfaces only. Switch P' is provided with a pair of contacts on each side of the "off" position. Two contacts u' and d' are longer than the others $f\,u$ and $f\,d$, so that the lever makes contact with the former before the latter. To avoid confusion, a wire is shown connected to the lever instead of carrying the current to it through sliding contacts, as is done on the switch shown in Fig. 36. An additional safety switch S is sometimes provided to stop the elevator in emergencies, but it is not in use under normal conditions.

79. Type of Motor Used With G. S. Controller. Before taking up the action of the controller, it will be well to consider briefly the type of motor used with this system of control. In order to get the elevator under way quickly, it is necessary that the motor should give a strong starting

torque. This is provided for by the series field. The shunt field furnishes the excitation after the motor has attained its speed. In addition to these two windings, a third, or extra-field, winding is provided. This winding aids in providing a field when the motor is being brought to a stop, by allowing it to act as a dynamo; it also aids to some extent in providing a strong field at starting. It should be remembered that a shunt-wound motor will run as a generator if it is disconnected from the mains when up to speed and a path provided between the brushes for it to send a current through; it is not necessary to reverse either field or armature connections in order to make it generate, as is the case with a series motor.

80. Operation of Controller on First Point.—Suppose that the car is to be run up and that the lever of *P'* is moved to the left until the arm comes in contact with the long arc *u'*, but does not touch the contact *f u*. The operating current then flows as follows, starting from point *18* on the + side of the potential switch: *18*, through coil of switch *H'*, through coil of the "up" magnet *D'*, through wire *u u* to stop-motion switch *M'*, to contact strip *u'*, by way of the horizontal strip, through flexible car-operating cable to contact *u'* on car-operating switch, through lever to *w*, thence through safety switch and wire *y y y* to the negative side of the potential switch. This current operates switches *D'* and *H'*. Switch *D'* is drawn up by the fine-wire coil and contact is made between *9*, *9'* and *10*, *10'*, as indicated by the dotted lines. This allows current to flow through the shunt field by way of the path +–*18*–*9'*–*9*–*D*– through shunt field–*H*–*19*–*20*. The operation of *H'* releases the brake by connecting points *16* and *16'*, because point *D* connects through *D'* to the + side of the circuit, and when *16* and *16'* are in contact, the other terminal of the brake magnet connects to the negative side of the circuit. This releases the brake and allows the motor to start as soon as current flows through the armature. When switch *H'* operates, points *17*, *17'* are separated so that

no current can flow through coil *k*, and, hence, switches *G'* are open so long as the motor is working. As soon as switch *D'* is forced up, switch *E'* makes contact between *7*, *7'* and *8*, *8'*, because of the connecting lever *1*, Fig. 6. The main current then takes the path indicated by the arrowheads as follows: *18–9'*, *10'–9*, *10–8–8'–I*–through armature of motor to *E*–through series coil of switch *E'–7'–7–14–H'–G'–3'–2'–4'*–through whole of starting resistance to *F*–through whole of series field to *H–19–20* to negative side of the circuit. The current through the series coil of *E'* holds the switch arm down firmly. The motor, therefore, starts up with the two sections of the series field and all the starting resistance in series with the armature. The extra field is in series with the resistance *r r'*, and the two together are in shunt with the armature. This is easily seen by tracing the path through the series field, beginning at point *D*, as follows: *D*–through extra field–*K'–4–r'–r–15'–15–14*–etc.

Fig. 39 represents, diagrammatically, the connections that are made on the first position of the switch *P'*. The

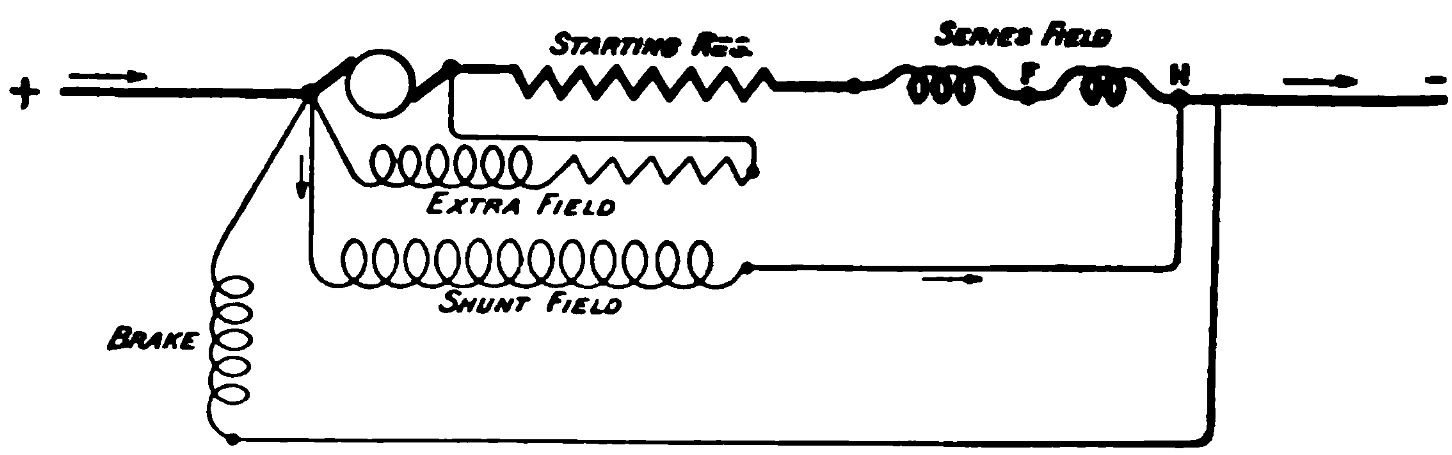


FIG. 39.

extra field does not supply nearly as much magnetizing power at starting as when the motor is stopping, because, at starting, the pressure across the armature terminals is small. On this point of the controller, therefore, the motor starts up, but would run the elevator at a slow speed because of the resistance in circuit. It should be noted that as long as the operating handle rests on *u'* or *d'*, the resistance switches *F'* are inoperative, because one terminal of coil *k* connects to contact *13* on switch *C'*, which is open.

81. Operation on "Fast Up" Position.—When the handle of *P'* is moved over farther, so as to make contact with the *f u* (fast up) contact, current flows through the solenoid of switch *C'*, thus forcing the switch lever up and making contact between *13*, *13'* and *14*, *14'*. At the same time contact is broken between *15* and *15'*, thus opening the circuit through the extra field, which is now no longer needed, as the motor is by this time well under way. The operation of this switch allows current to flow through the magnet coil *h* and resistance *x'*, as indicated by the dotted arrows, beginning at point *21*. This operates the group of switches *F'*. First *2* and *2'* are connected, thus cutting out the first section of resistance, then *3*, *3'*, cutting out the second section, then *G*, *G'*, cutting out what is left of the resistance and also one half of the series field; finally, *H* and *H'* are connected, thus cutting out the other half of the series field. The motor has now attained its maximum speed, and the path of the main current is +-*18-9'*, *10'-9*, *10-8-8'-I*-through armature-*E-7'-7-14-H'-H-19* to negative side of circuit. The motor now operates as a plain shunt machine with no resistance in circuit.

82. If the operating switch were moved in the reverse direction, switch *E'* would be moved up and switch *D'* would be down, as can be readily seen by tracing the connections. The main current then takes the path *18-6'*, *5'-6*, *5-12-12'*-through series coil of *D'-E*-through armature-*I-11'-11-14*, and so on as before. The current in the armature flows in the reverse direction to what it did before, while the current in the fields remains unchanged; the car, therefore, moves down.

83. Action of Controller on Slowing Down and Stopping.—Suppose that the elevator is running on the "fast up" point and that the handle is moved back until it leaves contact *f u*, but still rests on contact *u'*. Switch *C'* will be opened, and this will cause switches *F'* to open, thus cutting the resistance and series field back into the circuit; the extra field will also be connected, because *15* and *15'* will

make contact, the resistance *r r* being in series with the extra field. Quite a large current will now flow through the extra field because the potential across the armature is high. When, therefore, the handle is moved back from the fast position, the field of the motor is greatly strengthened and all the resistance is cut back into circuit, thus rapidly lowering the speed of the motor. On account of the decrease in speed and the cutting in of the resistance, the pressure across the brushes is considerably decreased when the handle is moved from the fast position. When the operating handle is moved to the off position, switches *D'* and *H'* are opened. *D'* breaks connection with the line, and *H'* sets the brake by separating points *16*, *16* and opening the circuit through the brake magnet. At the same time, points *17*, *17'* are brought into contact, thus connecting coil *k* across the armature terminals. The pressure across the armature terminals is large enough to cause switches *4*, *4'* and *1*, *1'* to close, thus cutting out *r' r* and connecting the extra field across the armature. The armature thus generates current, which takes the path *1*–*8'*–*8*–*D'*–extra field–*K'*–*4*–*4'*–*14*–*7*–*7'*–*E*. The current through the extra field remains in the same direction as it did when the motor was run from the line and hence assists in keeping the field magnetized and bringing the motor to a stop quicker than if the shunt field only were used. As the motor slows down, the magnetization supplied from the shunt-field coil diminishes; hence, the provision of the extra field supplied with the current that the motor furnishes when running as a generator greatly increases the braking action. The generating action soon slows the motor down, and as the pressure across the armature terminals decreases, switches *4*, *4'* and *1*, *1'* open in succession, because *K'* is no longer able to hold them. This cuts resistances *r'*, *r* back into circuit with the series field, thus making a smooth stop and leaving the resistances *r*, *r'* in series with the extra field ready for the next start. Of course, while this action is taking place, the band brake is also on because the dynamo-braking action decreases as the speed decreases,

and hence would not answer, in itself, for bringing the motor to a full stop. All these actions take place in a very short space of time, but the effect is to stop the motor smoothly and quickly, and the car is at all times easily controlled by switch *P'*, the cutting out of the resistance and the connections necessary to produce the dynamo-braking action being made automatically.

84. The stop-motion switch *M'* merely brings about automatically the same connections that *P'* should, in case the operator failed to move *P'* when the car reaches the limit of its travel. When the contact arm is swung around by the action of the traveling nut, as already explained, contact is first broken, if the car is ascending, between the *f u* and *f* contact arcs, thus slowing down the motor; and as the car travels still farther, contact is broken between arcs *u* and *u'*, thus applying the brake and stopping the car.

OTIS NO. 6 MAGNET CONTROLLER.

85. General Description of No. 6 Controller.—Fig. 40 shows the general arrangement of the Otis No. 6 magnet controller. This is a later type than the G. S. controller previously described, and although its mechanical details are quite different, its principle of operation is almost identical. The resistance, which is usually in the form of cast-iron grids for controllers of large capacity, is arranged behind the board and does not appear in the figure. The various switches are marked *A'*, *B'*, *C'*, *1*, *2*, *3*, *4*, *5*. Switches *A'*, *B'*, *C'*, and *1* are operated by the car-controlling switch; the other switches operate automatically. Whenever a switch, for example *C'*, operates, its plunger *c* is drawn up, thus bringing the copper disks *d*, *d'* up against the contact fingers *f*, *f'*. When a switch is deenergized, its plunger drops and the disks make contact with the lower fingers where any are provided. When a disk is drawn up, it first makes contact with the auxiliary carbon contacts *x*, and as it is pulled up still farther, it bears against a copper

contact on a finger hinged at the same point as the finger that carries the carbon contact. When a disk drops, it first breaks contact at the copper surfaces, and the final break

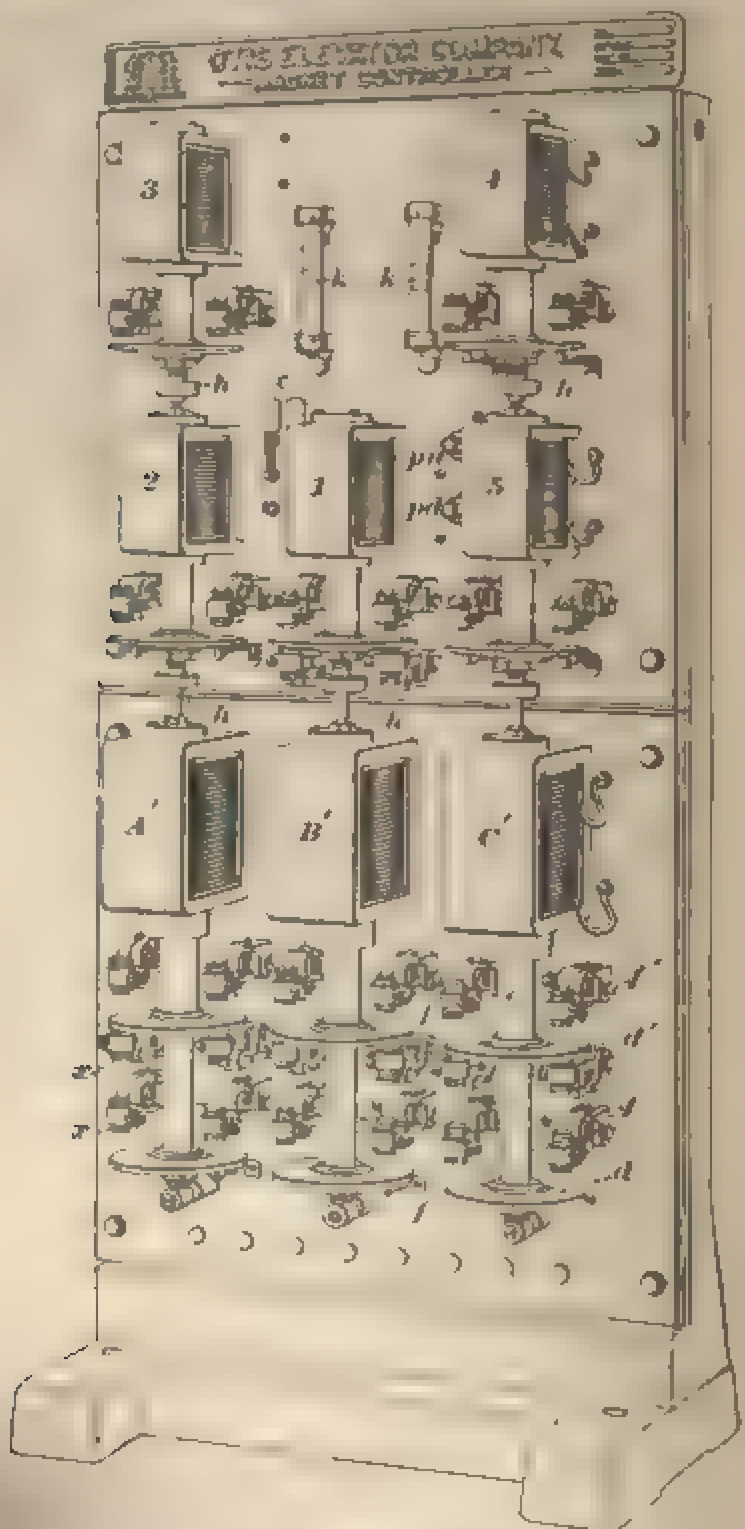


FIG. [illegible]

[illegible] is between the copper and the carbon terminal, so [illegible] is no danger of sticking. The carbon pieces are [illegible] so as to prevent their working loose and sliding

through the holders. The plungers with their contact plates are free to revolve, and the motion of the switch gradually works them around so that whatever burning takes place is spread around the whole disk instead of in one place only. Switches *2*, *3*, *4*, and *5* operate automatically, one after the other, and the voltage at which they operate is adjusted partly by regulating the initial position of the plunger by means of the adjustable stops *h*, and partly by inserting a resistance in series with each solenoid. The main fuses are shown at *k*, *k*; they are of the enclosed type. The small knife switches shown at *c* are used for cutting off the car-controlling switch, so that the motor cannot be started from the car. Push buttons *p u* and *p d* are used to allow the motor to be operated from the board. These devices are very useful when tests are being made to locate trouble, but under ordinary working conditions they are not in use. Switches *A'* and *B'* control the direction of motion of the car. When *A'* operates, the car descends, and when *B'* operates, it ascends. Switch *C'* closes and opens the main circuit.

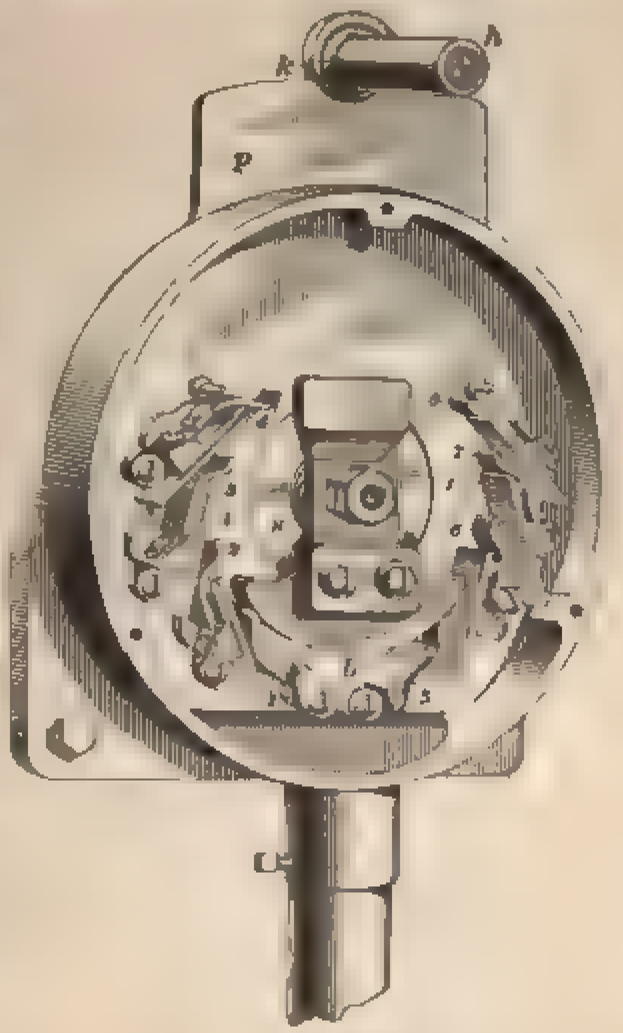
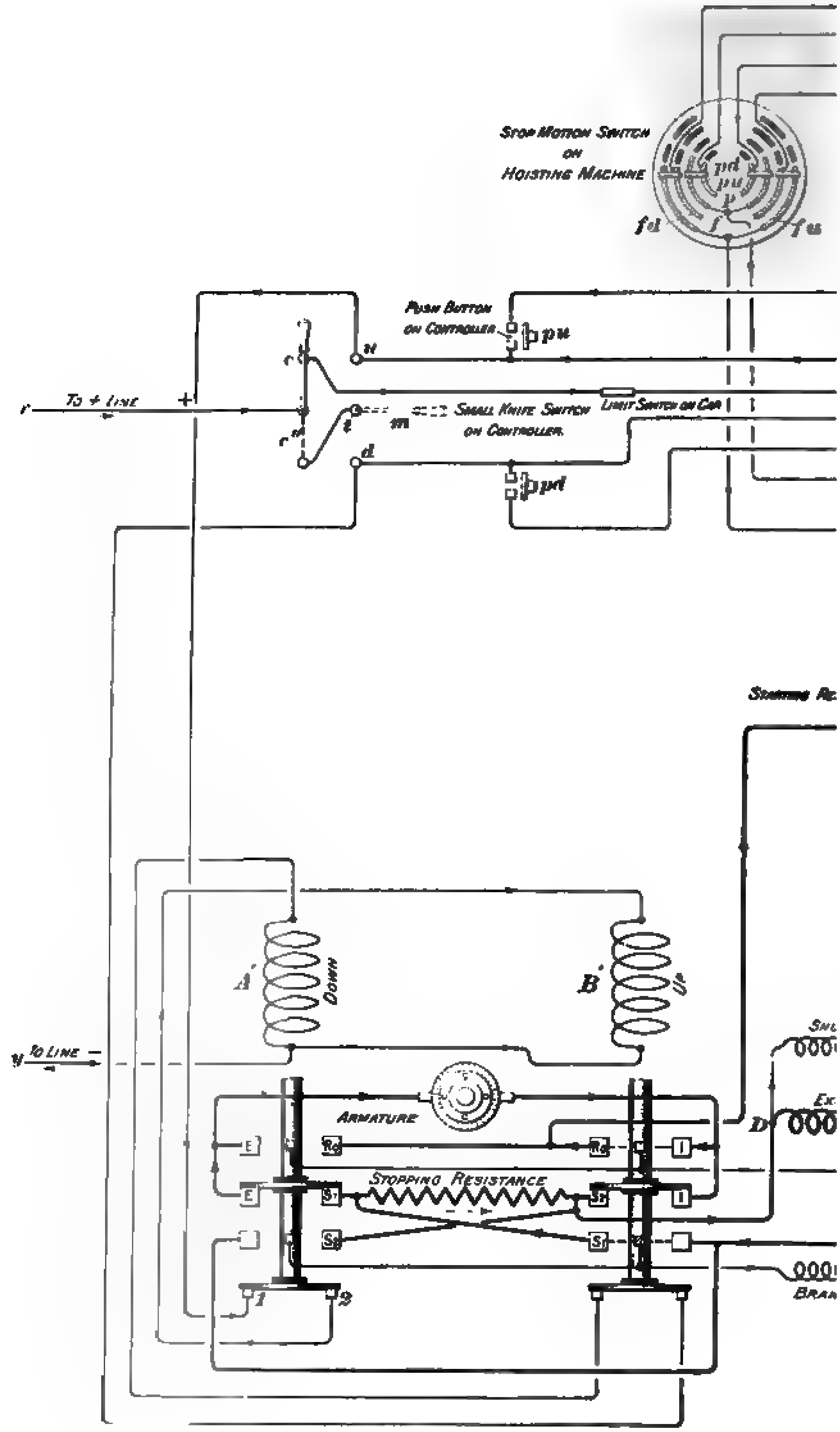


FIG. 41.

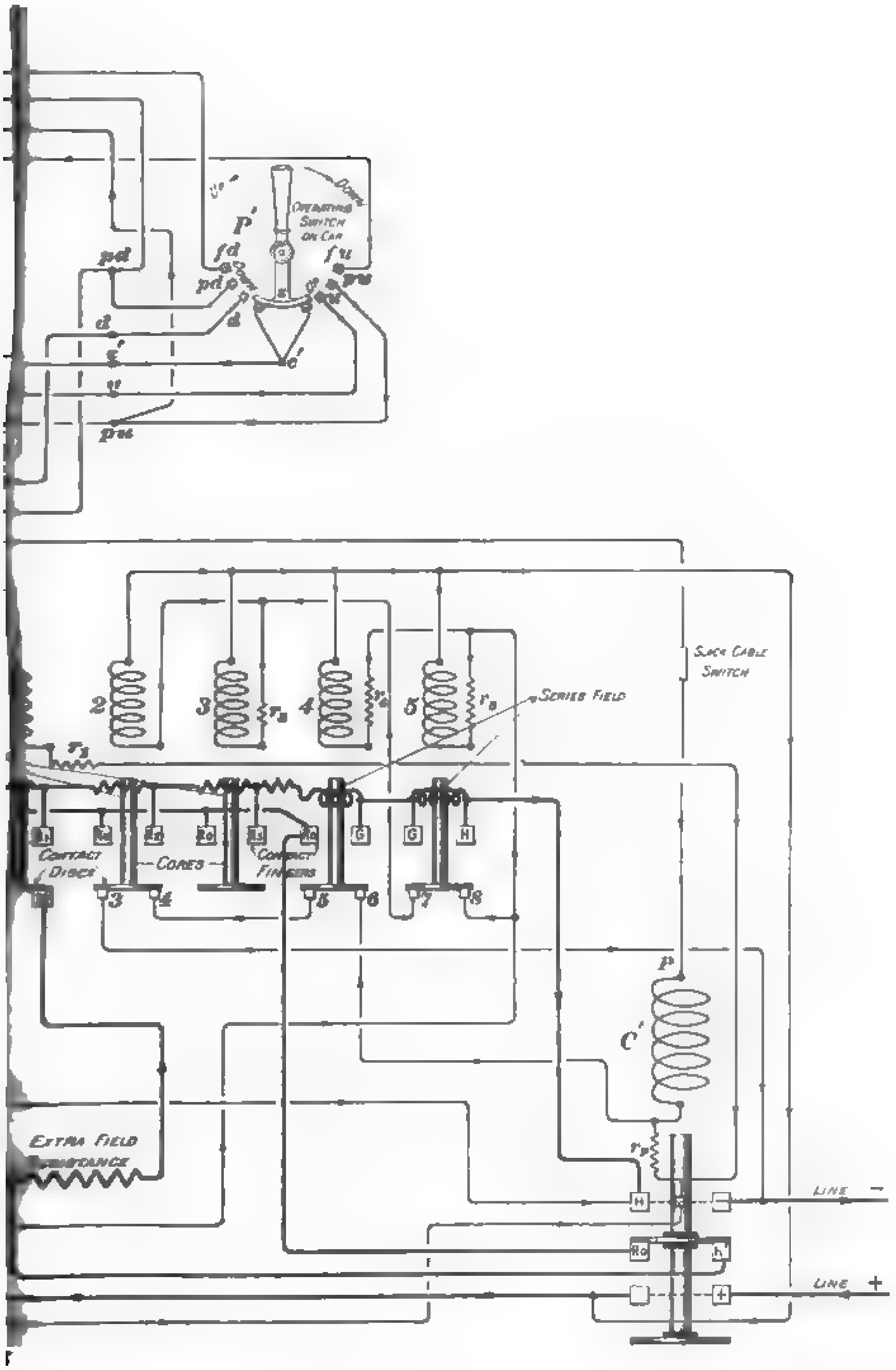
86. No. 6 Car-Controlling Switch.—Fig. 41 shows the car-controlling switch used with the No. 6 controller, the cover being removed in order to show the working parts. The operating handle is shown at *h*, and it normally occupies the central, or off, position. When moved to the left, the car ascends, and when moved

to the right, it descends. The arm carries a contact arc *b* that makes contact with the fingers *1*, *2*, *3*, *4*, etc. when the handle is moved from its central position. The arc *b* is of such a length that when the handle is moved to its extreme position in either direction, it makes contact with all four fingers on the side to which it is moved. The handle *h* is held at the central position by means of a spiral spring *s*, so that if the operator releases the handle, it at once returns to the off position. When the handle is at the off position, the projecting rim *k* rests in a notch in the plate *p*, and in order to move the handle, it must first be pulled out against the action of a spring. Insulating pieces *i* are inserted between the fingers, as shown, in order to avoid short-circuiting.

87. Connections for No. 6 Magnet Controller.—Fig. 42 shows the connections of the No. 6 controller. In this diagram the positions of the switches, resistances, and motor armature and field windings have been arranged so as to make the diagram simpler and easier to follow than if the various parts were located in the same positions that they occupy on the controller. The connections are, however, the same as used on the controller shown in Fig. 40, and corresponding switches are lettered alike. The operation is on the whole very similar to that of the G. S. controller. Terminal *x* of the operating circuit is connected to the + line and terminal *y* to the − line. By throwing the small switch *c* down into the dotted position *c''*, the car cannot be operated from *P'*. Switch *m* is normally open, but it can be thrown so as to connect *t* and *d* or *t* and *u*. If *c* is thrown down to the position *c''* and *m* is thrown down so as to connect *t* and *d*, magnet *A'* is energized, and if push button *pd* is then pressed, current will flow through the coil of *C'* and the elevator will move down. If *m* be thrown up so as to connect *m* and *u* and button *pu* pressed, switches *B'* and *C'* will be operated and the car will move up. In other words, the small switches and push buttons allow the machine to be operated from the controller while the switch *P'* is cut off.


Stop Motion Switch
on
Hoisting Machine
Push Button
on Controller
pu
To + Line
Small Knife Switch
on Controller.
Limit Switch on Car
pd
A'
Down
B'
Up
To Line −
Armature
Stopping Resistance
D

F


OPERATING SWITCH ON CAR
SLACK CABLE SWITCH
SERIES FIELD
CONTACT DISCS
CORES
CONTACT FINGERS
EXTRA FIELD
LINE −
LINE +

88. Operation of No. 6 Magnet Controller on Starting Position.—Assume that the operating handle is moved to the left so as to bring the arc z in contact with u. Starting from x, the path of the operating current will be as indicated by the arrows through the coil of B' to the negative terminal y. Note that this current passes through the small contacts *1* and *2* of switch A', so that unless switch A' is down, B' cannot be drawn up, and it is impossible, therefore, for both switches to be drawn up together. When z is moved still farther so as to bring it in contact with the finger $p\,u$, a current is set up through the operating circuit, which includes the solenoid of switch C'. This current may be traced as follows: x–c–c'–$p\,u$–$p\,u$ to contact $p\,u$ on stop-motion switch–p–P–through solenoid of C'–*6*–*5*–*4*–*3* to line. This current operates C', which closes the main circuit, releases the brake, and connects the shunt field and extra field across the armature. The various paths of the current are indicated by the arrows, bearing in mind that B' and C' are now up. A powerful magnetic field is provided by the series coils, and as the motor comes up to speed, switches *2*, *3*, *4*, and *5* operate, thus short-circuiting the resistance and the series field. For example, when switch *2* closes, the main current passes from terminal R_0 to R_2, thus short-circuiting the first two resistance sections. When the handle of P is advanced so that z makes contact with finger $f\,u$, switch No. *1* is operated. This breaks connection between R_0 and M, thus cutting out the extra field. The switches are now all up except A' and the motor runs with a shunt field only; the resistance is all cut out and the motor runs at its maximum speed. When C' is up and when switch *2* operates, contact is broken between the small terminals *3* and *4*, so that the current through C' has to take the path through the resistance r_p to the negative side of the circuit. This resistance is inserted to prevent undue heating of C' and also to save current. Also, when switch *5* is operated, the current through the coils of *2* and *3* is cut off, thus preventing these coils from heating and cutting off the current necessary to energize them. When the core of *2*

drops, contact is established again between points *3* and *4*, but in the meantime it has been broken between *5* and *6* so that the current through C' still flows through the resistance r_p. The coils of *1*, *4*, and *5* have considerable resistance in series with them and do not overheat. It is, of course, necessary that these three should remain up while the motor is running, otherwise the extra field resistance, and series fields would not be cut out, while with switches *2* and *3* it is not necessary that they should remain up after sections *2* and *3* of the resistance have been cut out. The voltage at which switches *2*, *3*, *4*, and *5* operate is adjusted by means of the resistances r_3, r_4, r_5, switch *2* having no resistance and, therefore, operating at the lowest voltage. When P' is moved to the right, switch A' is energized and the elevator descends because the direction of the current through the armature is reversed, while that in the fields remains the same as before. The action of the stop-motion switch is the same as in connection with the G. S. controller and needs no special description.

89. Operation of No. 6 Controller on Stopping.— When P' is moved back, contact is first broken with the *fu* finger. This drops switch *1* and cuts one section of resistance into circuit as well as connecting points R_0 and M, thus cutting in the extra field. When contact is broken with finger *pu*, all the resistance is cut in and the main circuit is opened because switch C' is dropped. In fact, the switches *2*, *3*, *4*, and *5* will likely operate before contact is actually broken between *z* and *pu*, if the operating switch is not moved too quickly, because the cutting in of the first section of the resistance and the extra field will lower the speed and thus cut down the E. M. F. applied to coils *2*, *3*, *4*, and *5*. When C' drops, the brake is applied because the circuit through the brake magnet is opened. When the main circuit is opened by C', the armature is still able to send a current around the local circuit E–S_1–through stopping resistance–D through extra field and extra-field resistance–M–R_0–R_0–R_0–I, because switch B' has not yet dropped.

This generating action through the series field, together with the brake, will soon stop the motor, even if P^v is not moved to the vertical position and connection broken with finger u. The car can, therefore, be stopped without the necessity of operating the direction-controlling switch. For example, if the elevator were making an up trip, stopping at each floor, the handle would be moved far enough to break contact with $p\,u$ only, and B' would remain up during the whole trip. When P^v is moved to the off position, switch B' drops and the stopping resistance is connected directly across the armature terminals.

AUTOMATIC ELECTRIC ELEVATORS.

90. General Description.—An automatic elevator is one that does not require a regular operator, but is so arranged that it can be controlled by the passenger. These elevators are largely used in private dwellings where the elevator is not used very frequently, and where it would not be desirable or convenient to have an elevator boy.

91. Automatic electric elevators are, with the exception of the controlling devices, similar to other direct-connected electric elevators. There are a number of different styles of them, but the general method of operation is about as follows: A push button is provided at each landing, and in the car there are as many push buttons as there are floors. A passenger at the third floor wishes, say, to go to the first floor. He presses the button at the third floor and the elevator comes up or down, depending on what location it may be in at the time, and when it reaches the third floor it stops automatically, at the same time unlocking the door. The passenger then gets in the car, closes the door of the elevator shaft, and presses the first-floor push button in the car. The car then descends until it reaches the first floor and stops there of its own accord. In the automatic elevator made by the Otis Company, the various devices are so arranged that when the elevator is once started by the passenger

it cannot be interfered with by any other person. Also, it is not necessary that the push buttons should remain closed while the elevator is in motion. All that is necessary is to press the button for an instant and then release it. Various safety devices are also introduced; for example, it is impossible to operate the elevator if any of the doors of the shaft are open, and no person on any of the floors can possibly start the elevator if anybody at any of the other floors is getting on or off. We will describe two types of Otis elevator provided with automatic control, and these will serve to illustrate the principle of automatic control in general. The two types are practically the same with the exception of the automatic floor controller, which is geared to the elevator drum.

OTIS AUTOMATIC ELECTRIC ELEVATOR.

92. General Description.—Fig. 43 shows an Otis automatic electric hoisting machine provided with their older type of floor controller. In general appearance it will be noted that the machine is much the same as those previously described in connection with magnet control. About the only difference is the addition of the floor controller shown at *C*. A spiral contact band *a* is mounted on an insulating drum, which is moved sidewise by a coarse screw as it revolves, so that the contacts *b* always press against the band. The various contacts *b* connect to the push buttons at the different floors. The controller *C* is used to determine the direction of motion of the car when any given button is pressed, and also to stop the car when it reaches its destination; its action will be understood when the electrical connections are described. The strip *b* is arranged in spiral form on the drum simply to avoid the use of a drum of large diameter.

93. Magnet Controller for Automatic Elevator.—Fig. 44 shows the magnet controller used with the automatic elevator. *M* is the main switch that controls the direction of rotation of the motor. A swinging armature *x* is hung as

shown, between the poles of the two ironclad magnets z, z'. When it hangs in the central position, the circuit is open. When a button is pressed, one or the other of the magnets is excited, depending on the direction in which the car is to move. The armature is drawn over and contact established between the swinging terminals y attached to the arma-

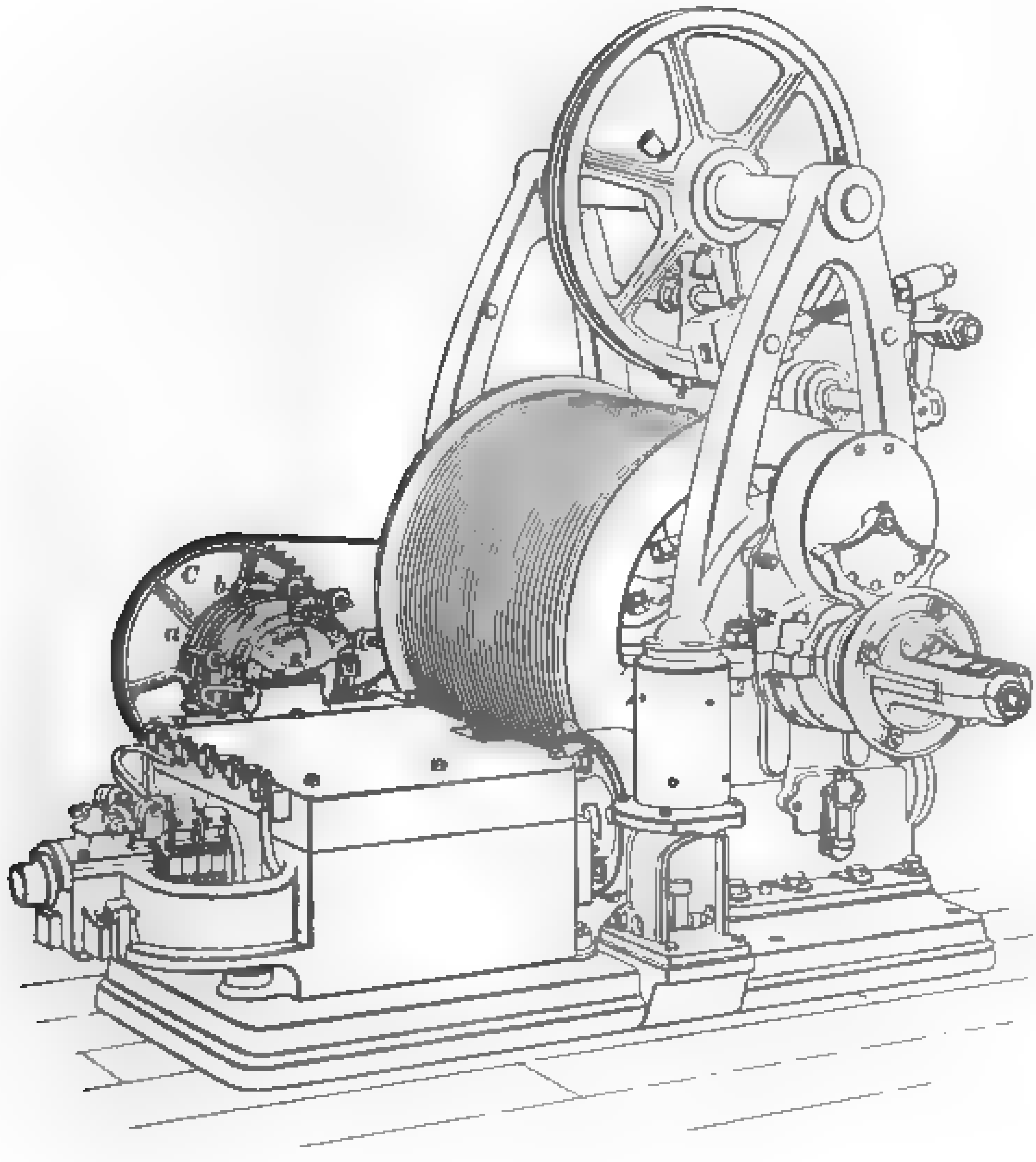


FIG. 43.

ture and the fixed terminals w. The pair of magnets C' cuts out the starting resistance, and magnet B' closes the main circuit and releases the brake. The devices shown at d, e, f, g, h, and k are known as **floor magnets,** and their function is to hold the push-button circuit closed

after it has been once pressed, even though the operator releases the push button itself; the reason will be explained later. Magnets, m, are provided to prevent interference with the elevator from other floors until the party who is already operating it is through.

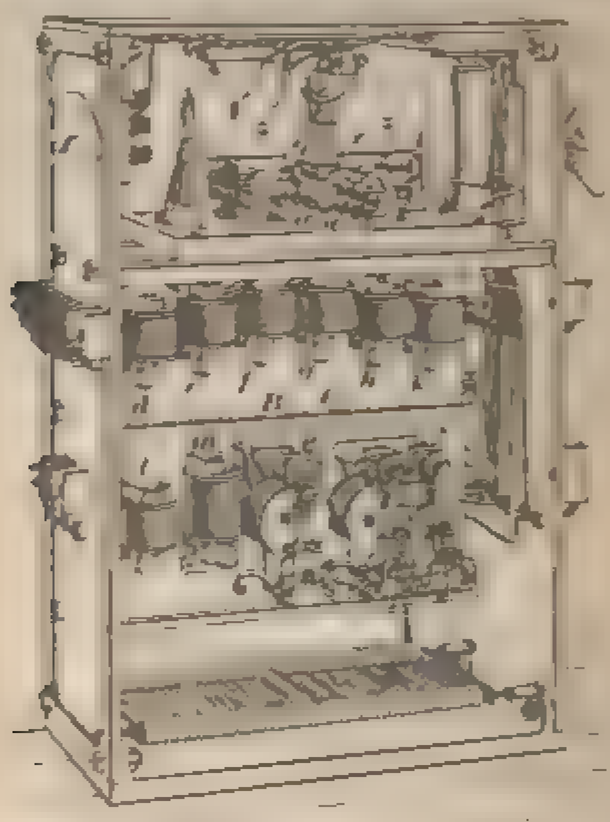


FIG. 44

94. Connections for Automatic Elevator.—Fig. 45 shows a diagram of connections for an Otis automatic elevator with the style of floor controller shown in Fig. 43. Like the preceding diagrams, the location of some of the parts has been changed in order to make the connections easy to follow. The diagram shows the connections necessary for the control of the elevator from four floors. A is the reversing switch; the open contacts are mounted on the swinging armature and the shaded contacts are fixed. When coil s is excited, the armature is drawn towards s, and the open contacts make connection with the lower row of fixed contacts as indicated by the dotted lines. We will assume that with the connections shown, the car moves up when coil s is energized and down when t is energized. Switch b closes the main circuit. 1, 2, 3, 4 are the small floor magnets shown at d, e, f, etc., Fig. 44. 1', 2', 3', 4' are the push buttons on each floor. 1'', 2'', 3'', 4'' are the push buttons on the elevator. d_1, d_2, d_3, d_4 are door contacts. These contacts are in series and are connected together as shown only when

all the doors of the shaft are closed. If any one of these contacts is open, i. e., if any door is not closed, it is impossible to start the elevator. The two switches for cutting out the resistance and the series-field coils are shown at c', and they are operated by magnet m'. C is the floor controller driven from the winding drum. The two segments a, a' represent the strips a shown in Fig. 43. On the drum itself they are put on spirally in order to allow a small diameter of drum, but here they are shown as two arcs, so that the connections may be more easily followed. With the position of the controller shown, the car is at the bottom of the shaft, i. e., at the first floor. As the car ascends, the controller turns as indicated by the full-line arrow, and a' slides from under *22'*, *33'*, *44'*, and u' in succession. At the same time, segment a comes in contact with *11'*, *22'*, *33'*, and *44'* in succession.

95. When switch A' is pulled by coil t, contact is broken between the auxiliary contacts *12*, *12'*, thus opening the circuit through coil s. Also, when A' is operated by coil s, contact is broken between contacts *13*, *13'*, thus opening the circuit through coil t. It is, therefore, impossible for both s and t to be excited at the same time. When switch c' makes contact at R_1, contact is broken between *14* and *14'*; when contact is made at R_2, contact is broken between *15* and *15'*. When the armature of magnet $m\ m_1$ is drawn up, contact is broken between points *9*, *9'*; when the armature of l is attracted, contact is made between points *10*, *10'*. When magnets *1''*, *2''*, *3''*, etc. operate, contact is made between *5* and *5'*, *6* and *6'*, etc. When buttons *1'*, *2'*, *3'*, or *4'* are pressed, contact is made between wire c and the wire running to the floor magnet corresponding to the button that has been pressed.

96. Operation of Automatic Elevator.—As already stated, the controller C indicates that the elevator is at the first floor. Finger *11'* is open-circuited, and, pressing either button *1* or *1'* would not start the elevator, because it is already at the first floor. Suppose a passenger wishes to get

on at the third floor and then go down to the first floor. He presses the third-floor button *3*, and the elevator moves up to the third floor and stops there, at the same time automatically unlocking the door of the shaft. After the passenger has entered the elevator and closed the door, he presses button *1* in the car and the elevator descends to the first floor and stops. The way in which the control is brought about will be understood by following the circuits in Fig. 45.

97. When button *3* is pressed, the operating current, starting from point *x* on the main + wire flows through the slack cable switch, through door contacts d_1–d_2–d_3–d_4, through cable to car and through safety button on car to A–A–A–m_1–[illegible]–*14*–*14*–*17*–*18*–*19*, through push button *3*–*3*, through floor magnet *3*–*33*–*33*–finger *33′*–strip a'–finger a–a–a–magnet s–*12*–*12*, through UL magnet of B', through limit switch on machine, through limit switches at bottom of shaft, to negative side of the circuit at y. This operating current accomplishes several results. In the first place, it closes magnet *3* so that contacts *6* and *6′* are brought together. This provides a path for the operating current that is independent of the path through push button *3*. The current can now flow along A A through coil m_1–r_1–*6*–*6′* through coil s, and so on as before. Consequently, after button *3* has been pressed the car will start up, even though *3* be released again, and it is not necessary for the passenger to keep the button pressed until the car reaches its destination. All that is necessary is to press *3* long enough to allow *3* to attract its armature. When the operating current takes the path through *6*–*6′*, a resistance r_1 is in circuit, as only a small operating current is needed to hold the armatures after they have been attracted. The operating current flows through s and one coil of switch B'. Hence, the reversing switch is pulled to the up position and the main circuit is closed, thus allowing the main current to flow as indicated by the arrows and starting up the motor. The operating of these switches also allows current to flow through the shunt-field coil and brake solenoid, thus releasing

the brake. When coils m, m_1 are energized, points *9*, *9'* are separated, thus breaking all connection between wire *A A* and wire *17*, *18*, *19*, which leads to one side of all the floor buttons; consequently, as soon as one button, in this case *3*, has been pressed, the buttons on all the other floors are cut out of service, and it is impossible for any other parties to operate the elevator. As the motor speeds up, switch R_1 operates because coil m' is connected across the armature terminals, and this cuts out the greater part of the resistance, at the same time separating points *14*, *14'*. When sufficient speed is attained, switch R_2 operates and cuts out the remainder of the resistance and the series field, at the same time separating points *15*, *15'*.

98. All the time that the car is going up from the first floor to the third, controller C is turning as indicated by the arrow, until, when the third floor is reached, a' slides from under finger *33'*, thus interrupting the operating current and stopping the motor. The motor is stopped by the band brake and no provision is made for a dynamic braking action, as these elevators are not intended for high-speed service.

99. After the car has stopped at the third floor and automatically unlocked the shaft door, the passenger slides back the door, thus opening the operating circuit at contacts d_3 and making it impossible for any persons on the other floors to start up the elevator while he is getting on. After closing the door and thus reestablishing contact at d_3, he presses button *1'*. This allows the operating current to flow as follows, starting from y as before: z–slack cable switch–d_1–d_2–d_3–d_4, through cable to safety button on car–A–A–A–through m_1–l–*15'*–*15*–c–c–c–c–*1'*–*1*–*1*–*1*–*11''*–*11*–*11*–*11'*–a–d'–D–t–*13*–*13'*–D L, through limit switch on machine, through limit switches at bottom of shaft to y. It must not be forgotten that by the time the elevator has reached the third floor, fingers *11'* and *22'* are resting on contact strip a, and hence are in connection with the wire D that runs to t. Switches B', A', and C' therefore operate as before, except that A' allows the current to flow through the

armature in the reverse direction and reverses the motor. Floor magnet *1''* makes contact between *8* and *8'*, so that the operating current will continue to flow even after the button *1'* is released. Contacts *9*, *9'* are also separated, so that the push buttons *1*, *2*, *3*, *4* are cut out while the elevator is in motion. Magnet *l* is excited and makes contact between *10* and *10'*, thus allowing current to flow to the negative line by the path A–m_1–l–$10'$–10–r_2– —, and this current holds *10* and *10'* in contact, even though the operating current through *1''* is interrupted by the controller *C* when the elevator reaches the first floor. When the elevator reaches the first floor, it is automatically stopped by the controller, as already explained, but contacts *9* and *9'* are still separated and contacts *10* and *10'* closed, because current still flows through the path z–d_1–d_2–d_3–d_4–A–A–A–m_1–l–$10'$–10–r_2– —. The result is that no one can interfere with the elevator because pushes *1*, *2*, *3*, *4* are cut out. This current through m_1 and *l* remains to flow until the door is opened, thus breaking the circuit at d_1 and allowing the armature of *m* and *l* to drop. After the passenger has gotten out and after the door has been closed again, thus bridging the break at d_1, the elevator may be operated from the other floors, but not before; thus avoiding the possibility of accident while the passenger is getting out.

By tracing out the connections and bearing in mind the action of the controller *C*, the student will see that the car is under complete control at all times, and that it is practically impossible for any person to interfere with the operation while another person is using it. The unlocking as well as the opening of the doors on these elevators is usually automatic.

OTIS AUTOMATIC ELECTRIC ELEVATOR WITH NO. 2 FLOOR CONTROLLER.

100. General Description.—The style of floor controller shown in Fig. 43 and indicated at *C*, Fig. 45, has been superseded by a later type shown at *C*, Fig. 46. Both styles are, however, in use, so that it has been thought

advisable to illustrate both of them. The floor controller in Fig. 46 is considerably different in construction, but it accomplishes the same results as the older type; it is mounted on top of the motor and driven by a chain *a* running over a sprocket wheel on the end of the drum shaft.

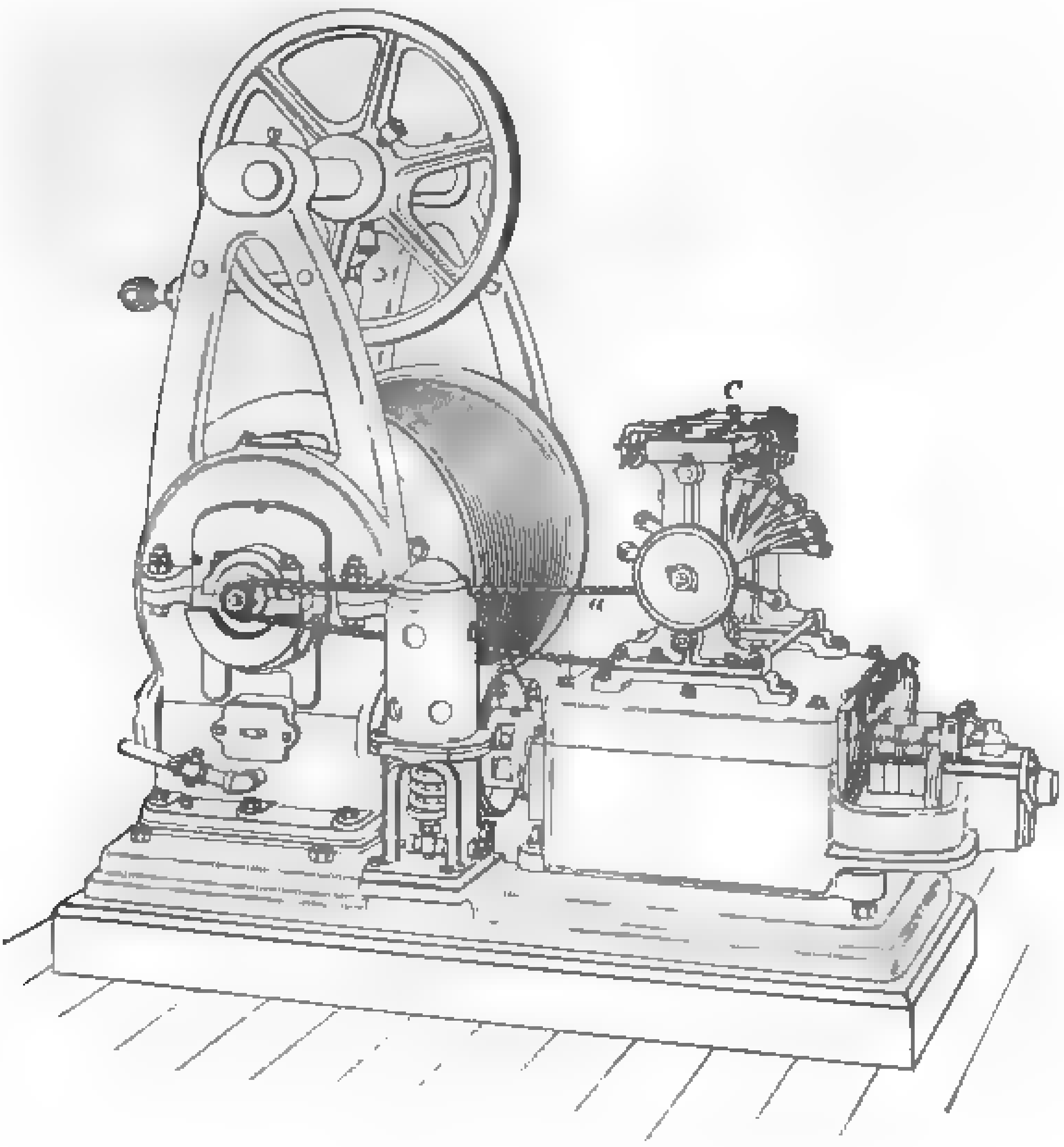


FIG. 46.

The controller *C* serves also as a limit switch, so that it is not necessary to provide the hoisting machine with the usual traveling nut operating a limit switch. Fig. 47 is a larger view showing one side of the controller. The sprocket wheel *s* is revolved by means of the chain, and by means of

[illegible] gearing [illegible] shaft [illegible] through [illegible] are propor-[illegible] [illegible]. On this shaft a [illegible] arms [illegible] each arm carrying a small [illegible] [illegible] arms [illegible] are [illegible] pivoted [illegible] cross-contact [illegible], the [illegible] indicated by [illegible]. [illegible] contact has a groove in [illegible] thus forcing up [illegible] and making connection between the two clips

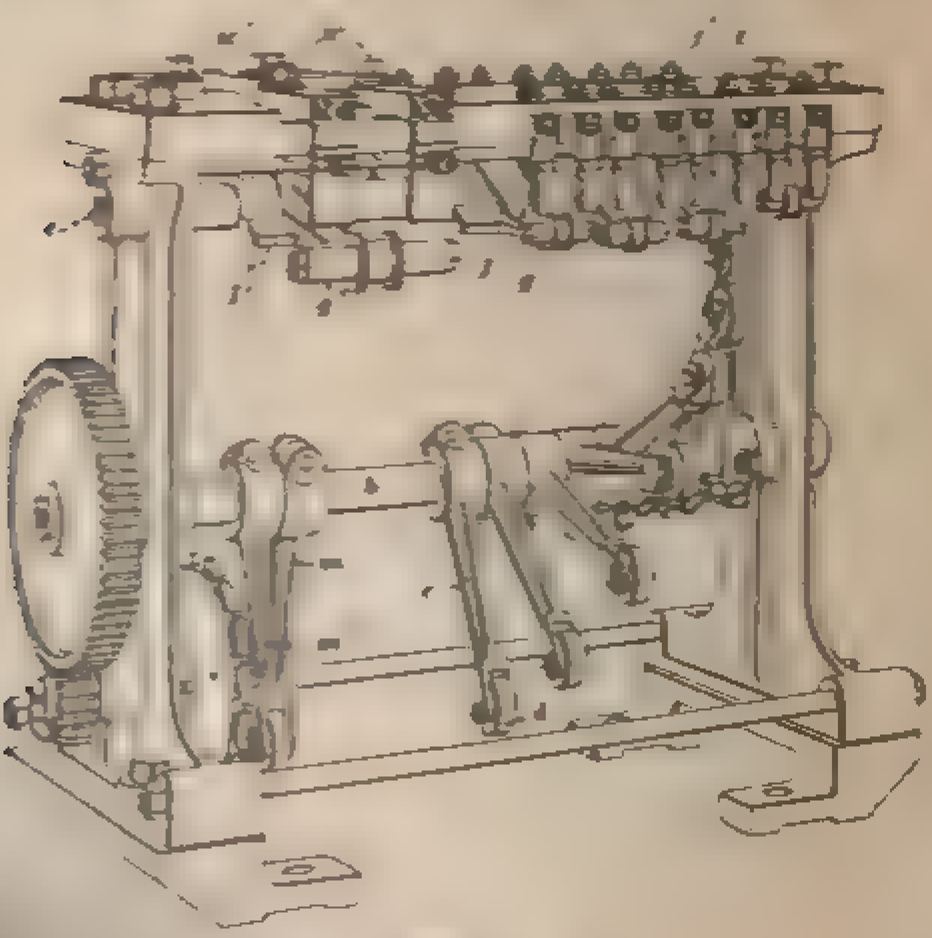


FIG. 6

with which it is brought in contact. There are two rows of [illegible] controller, together with a corresponding number of arms, cams, and cross-contact pieces. The two pairs of large terminals shown at [illegible] [illegible] the main circuit contact being made between [illegible] by means of the large cross-contact piece g and a sim-[illegible] on the other side of the controller. These two main [illegible] are operated by the arms [illegible]. This controller accomplishes the same result as the one shown at C in

Fig. 43, but uses a series of mechanically operated switches in place of a series of brushes with a sliding contact.

101. Connections for Otis Automatic Elevator With No. 2 Floor Controller.—Fig. 48 is a diagram of connections for this type of controller. It will be noted that it is very similar to Fig. 45, the limit switch on the machine and switch *B'* being omitted. The up-and-down magnets on switch *A'* are reversed in position from that in the first diagram, but this is immaterial, as the direction of rotation of the motor may be kept the same in both cases by reversing the armature terminals at the motor. The two large cross-contact pieces on the controller are shown at *g'*, *g''*, and the small contacts are indicated at *11'*, *33'*, *22''*, etc., there being but three small movable contacts on each side in the diagram, because the elevator is controlled from four floors only. With the diagram as shown, the car is supposed to be at the first floor. All the left-hand contacts of the controller are out and all the right-hand ones are in, connecting the floor magnets to the *n* line and allowing current to flow through the up magnet of switch *A'* when any one of the push buttons *2*, *3*, or *4* is pressed. As the car moves away from the first floor, *11'* closes, and when it reaches the second floor, *22'* opens. As it moves away from the second floor, *22''* closes, and when it reaches the third floor, *33'* opens; and so on. When the car reaches its upper limit of travel, switch *g'* is opened and when it reaches its lower limit, *g''* is opened, thus cutting off the main current. When the elevator descends, the switches open and close in the reverse order. The small arrowheads show the path of the operating current when button No. *3* is pressed to bring the car up to the third floor. The large arrowheads show the path of the main current. It will not be necessary to trace these through, since outside of the part through switch *C* they are practically the same as explained in connection with Fig. 45. Ordinarily, the switch *A'* would open the main circuit and switches *g'* and *g''* are intended more as a safety device in case *A'* does not operate.

SPRAGUE-PRATT SCREW ELEVATOR.

102. General Description.—The hoisting mechanism of this elevator differs in a marked degree from those previously described; Fig. 49 shows the general construction. It has no winding drum, the cable being taken up over a number of multiplying sheaves. The hoisting rope H, or rather set of four ropes, passes over the fixed sheaves S' and movable sheaves S and is anchored at A. The motor M revolves a long screw E, which is directly coupled to the motor shaft. On this screw is a nut N, which is not connected in any way with any other part of the mechanism. A crosshead carrying sheaves S is arranged to slide on the base B, and when screw E is revolved by the motor, the nut bears against the crosshead and moves the sheaves S to the right, thus taking up the cable and raising the car. The construction of the nut N and the sheave bearings is such that there is very little friction, and the efficiency of the hoisting mechanism is so high (about 70 per cent. from car to motor) that when the car is descending, the pull against the crosshead revolves the screw and motor in the reverse direction, thus driving the motor as a generator. The sheaves are usually designed to give a multiplication of 8 to 1, so that the amount of rope that the machine takes up is 8 times the travel

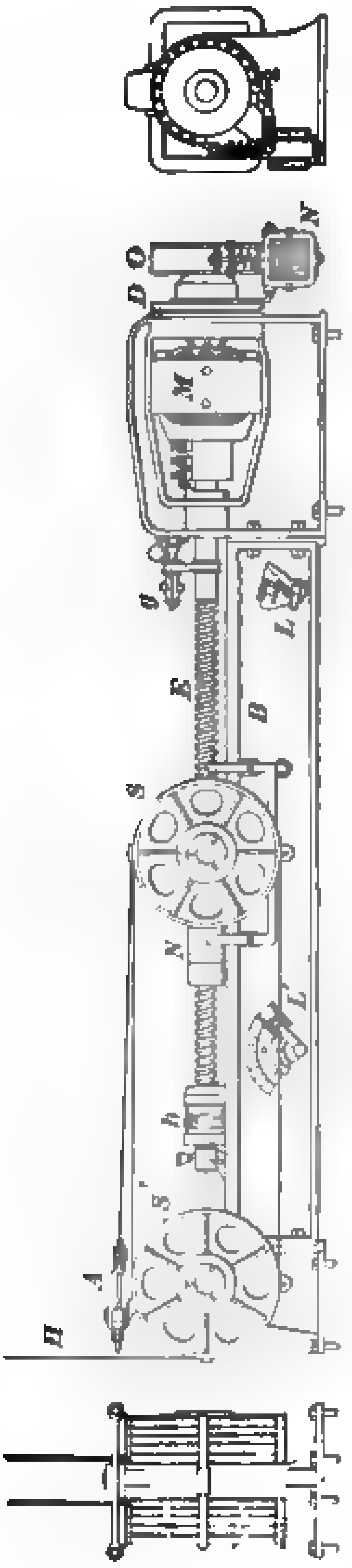


FIG. 49.

of the screw. For high rises and high speed, there is a further multiplication of 2 to 1 on the counterbalance. The ropes lead from the car over the overhead sheaves, down around a sheave on the counterbalance, up to and anchored at the top of the building. The ropes leading to the machine are attached to the bottom of the counterbalance. There are four of these ropes, as indicated in the end view, Fig. 49, two of them passing around the eight sheaves on one side of the machine, and the other two passing around the eight sheaves on the other side. The travel of the car is, therefore, 16 times that of the nut. The screw E is always under tension, no matter what the load on the elevator may be and no matter whether it be moved up or down. This is necessary with this type of elevator because the construction of the nut and screw is such that the pressure between them must always be in the one direction, and the tension on the rope is the only driving power that the elevator has when descending. These machines are not, therefore, overbalanced.

103. Motor.—The motor used with the Sprague-Pratt elevator is of the ordinary direct-current four-pole type with compound field winding. It is mounted at the right-hand end of the machine, as shown at M, Fig. 49, and needs no special description.

104. Transmitting Devices.—The transmitting devices of this elevator are of special interest. The use of the screw, traveling nut, and sheaves makes the action similar in many respects to that of a hydraulic elevator. The sheaves are mounted on roller bearings so as to run with little friction, and the traveling nut is arranged so that the thread of the screw bears against balls. Fig. 50 shows a section of the **ball nut**. Steel balls a are arranged as shown, and when the screw turns, these balls revolve and work their way along through the nut, passing in at one end, traveling through the nut, and returning by way of the channel b in one side. The rolling friction of such a

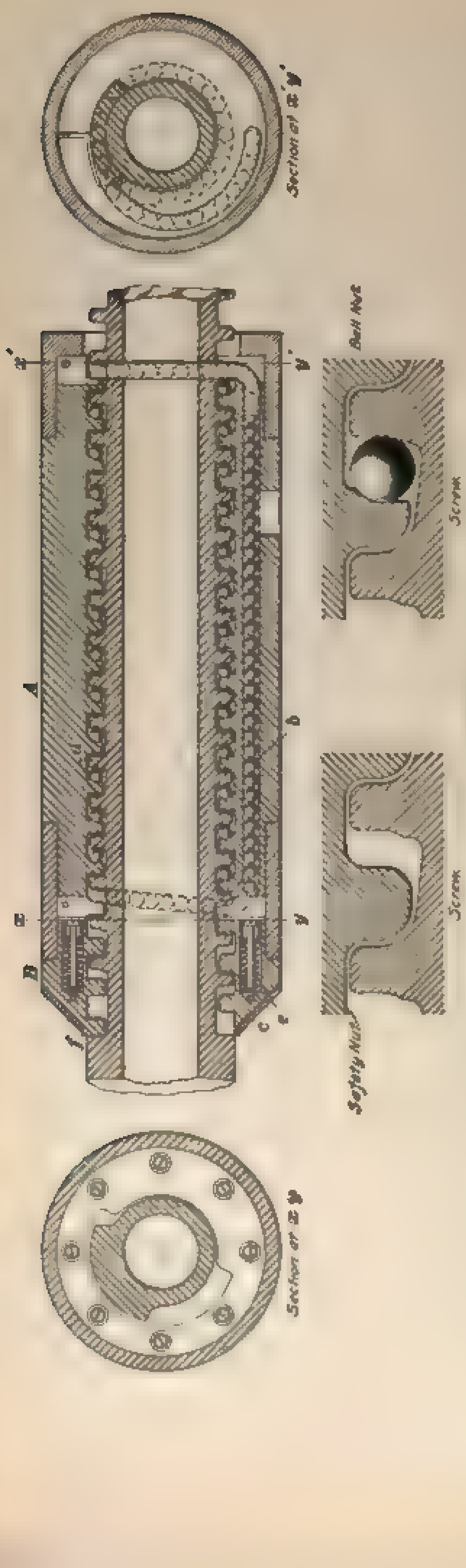


FIG. 30.

nut is very much less than the sliding friction of an ordinary nut. In addition to the ball nut A, there is provided a safety nut B, which is without balls, because under ordinary circumstances there is no pressure taken up between its threads and those of the screw. The safety nut is provided for two purposes, namely: to prevent slack cable and also to hold the crosshead in case the threads on the ball nut or screw should strip. This last contingency is something that never occurs if the elevator receives any kind of inspection, but as these elevators are intended for passenger service, it is advisable to take every possible precaution. When the car is drawn up, there is a thrust between the conical bearing c and the crosshead that carries the movable sheaves, and since the friction of this conical bearing is much greater than the friction of the

screw, the nut does not revolve, but travels along the thread, thus pushing the crosshead and raising the car. When the car descends, the pull on the rope runs the screw backwards, and with it the motor, which now runs as a generator. When the pressure on the nut is released, the screw continues to revolve on account of the momentum of the armature, and the cable would be slackened if the nut did not revolve with the screw. As soon, however, as the pressure on bearing *c* is released, springs *e*, which are normally compressed, force nuts *B* and *A* apart, thus bringing the threads of the safety nut into contact with those of the screw and producing enough friction to make the screw and nut revolve together and thus hold the crosshead stationary. Again, if the threads of the ball nut should wear excessively, or strip, the pressure is taken up on the safety nut, which then revolves with the screw and indicates the defect. A buffer *h*, Fig. 49, is provided for the nut to strike against when it reaches the limit of its travel corresponding to the lowest position of the car. When it reaches the upper limit, the end of the nut comes up against the shoulder *f*, Fig. 50, and any further turning of the screw simply causes the nut to revolve with it. The nut shown in Fig. 50 is the later type using a hollow screw of large diameter with $\frac{5}{8}$-inch balls. The balls used on earlier types of the machine were $\frac{1}{2}$ inch in diameter, but this size was found to be rather small. The nut shown contains 320, $\frac{5}{8}$-inch balls. The nut used formerly had 240, $\frac{1}{2}$-inch balls.

105. Thrust Bearing.—The thrust of the screw is taken up by a special form of thrust bearing, which is located at *D*, Fig. 49, on the back end of the motor frame. The thrust is taken up on a large number of small rolls placed between two hardened steel plates. One plate is carried by the field yoke and the other revolves with the shaft. The small rolls, 180 in number, $\frac{1}{2}$ inch in diameter by $\frac{3}{16}$-inch face, are placed in openings, arranged in spiral form, in a bronze plate. A plate containing these rollers is shown in

Fig. 51; this is placed between the two hardened plates previously mentioned, and the whole thrust bearing is arranged so as to run in oil.

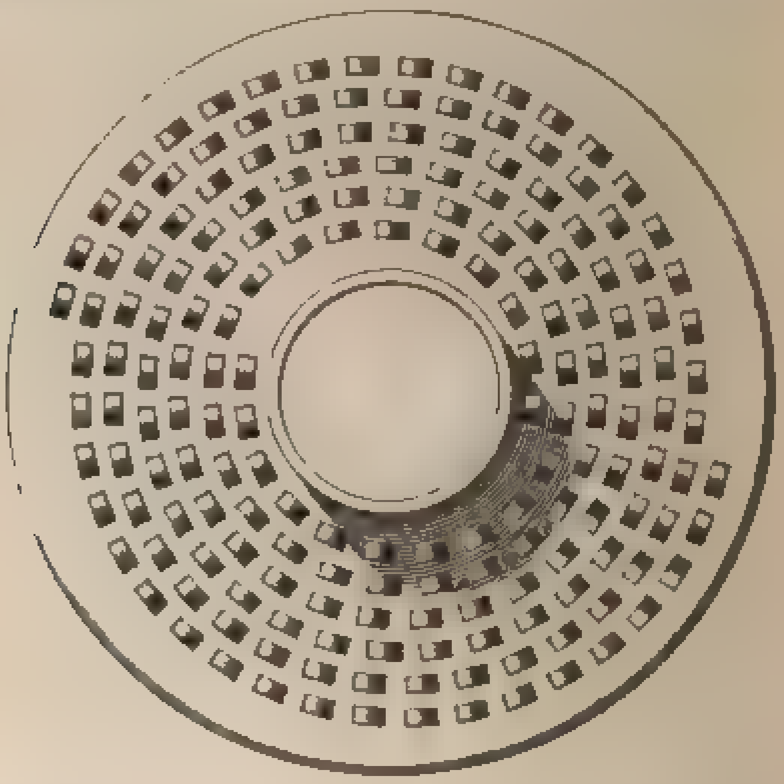


FIG. 51

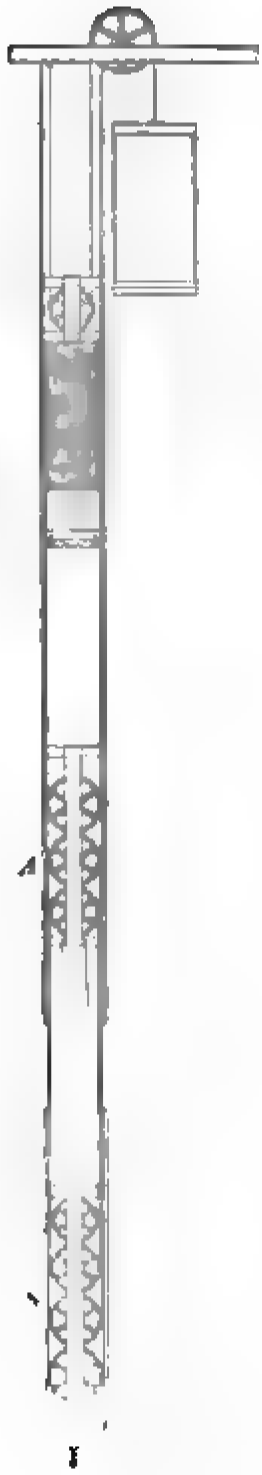
106. Brake.—The elevator is provided with a band brake controlled by a solenoid. This brake is shown at O, Fig. 49, and consists of a steel band lagged with wood. The band covers about three-fourths of the circumference of the brake wheel. The solenoid N operates against a spring, so that when the magnet is excited the brake is released, and when it is demagnetized the brake is at once applied by the spring.

107. Limit Switches.—Two limit switches L and L', Fig. 49, are mounted on the base and are operated by projections on the traveling crosshead, so that if the sheaves reach the limit of their travel in either direction, the motor is stopped. Switch L is ordinarily closed, and when the car reaches the upper limit of its travel it is opened, thus opening the main circuit and applying the brake. When the car is descending, switch L' is normally open and when L' is operated at the lower limit it is closed, thus cutting in a

resistance across the motor and gradually cutting it out with further motion of the crosshead. A centrifugal governor *g* is belted to the screw, and if the speed exceeds the allowable limit, this governor opens a circuit and effects an application of the brake.

108. Method of Control.—The method of control used with the Sprague-Pratt elevator is similar in many respects to the magnet-control method previously described. The magnet type of controller might be used with this type of elevator, but many of the Sprague-Platt machines are equipped with a controller in which resistance is cut out by means of a sliding arm moved by a small *pilot motor*. The closing of the main circuit and the reversing of the motor is accomplished by means of electromagnetic switches very similar to those shown in Fig. 40. The pilot motor is under the control of the car operator and is operated by means of a car-operating switch in a manner similar to that already described in connection with magnet control.

109. Sprague-Pratt Vertical Type Elevator.—Most of the Sprague-Pratt machines have been of the horizontal type shown in Fig. 49. In cases where two or more elevators are required, these horizontal machines are placed one on top of the other, thus economizing space, but a number of machines have been built so that they may be placed vertically in the same way as a hydraulic elevator. Fig. 52 shows the general arrangement of one of these vertical machines. The motor *M* is at the bottom of the shaft. The fixed sheaves *A* are mounted just below the lower limit of the counterbalance, and the movable sheaves *S* travel up and down in guides. The rope running to the sheaves is fastened to the under side of the counterbalance, and there is a multiplication of 2 to 1 between the counterbalance and the car, as indicated. The vertical type has some important advantages over the horizontal type. In the horizontal type, the long screw always tends to sag more or less, thus producing uneven wear. This sagging effect also produces uneven wear on the motor bearings and on the thrust bearing.



When the machine is placed in the vertical position, these effects are done away with entirely, and the additional advantage is gained that the weight of the screw, armature, and sheaves tends to counterbalance some of the thrust and thus reduces the effective pressure on the thrust bearings.

FRASER DIFFERENTIAL ELEVATOR.

110. General Description.—This elevator has not as yet been widely used, but as it is very simple in construction and easily controlled, it is probable that it will prove valuable for many kinds of service. It is manufactured by the Otis Elevator Company. The principle on which the elevator operates is an interesting one and will be understood by referring to Fig. 53; *A* is the car; *B* and *C* two pulleys that revolve in opposite directions, as shown. *W* is the counterweight and *D* an endless rope passing over the pulleys *B*, *C*, and around pulleys *E* and *F* on the car and counterweight. Pulleys *B* and *C* are driven by independent sources of power, so that their speed with regard to each other may be changed. If the circumferential speed of *B* is exactly the same as that of *C*, it is evident that the rope *D* will simply pass around over the pulleys and the car will remain stationary. If, however, the circumferential speed of *C* is made greater than that of *B*, the rope will be passed over *C* faster than it is taken up by *B* and the car will descend. If the circumferential speed of *B* is greater than that of *C*, the rope will be taken up by *B* faster than it is paid out by *C*, and the car

will ascend; the greater the difference in circumferential speed, the greater is the speed of the car. It should be noted that the action depends on the difference of *circumferential speed*, or upon the difference in speed at which the rims of sheaves B and C travel. Pulleys B and C may or may not revolve at the same speed when the car is stationary, depending on whether or not they have the same diameter.

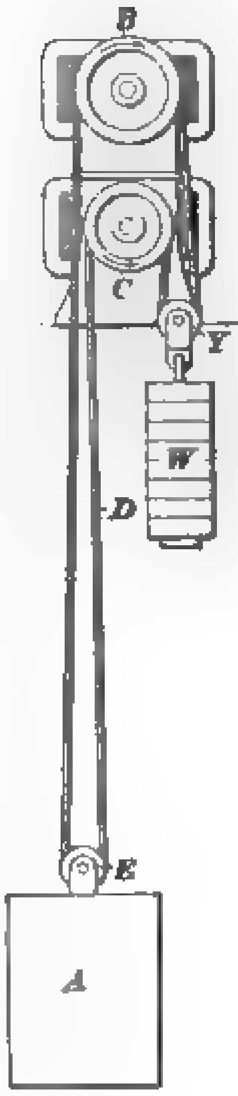


FIG. 53.

This type of elevator allows the car to be stopped, raised, and lowered without stopping or reversing the driving motors. This, of course, is a great advantage. Usually electric motors are used for driving B and C, though steam engines or a combination of engines and motors could be used. Another advantage of this elevator is that it does not require a winding drum with its accompanying gearing.

111. Fig. 54 shows the general arrangement of an elevator embodying this principle and driven by means of two electric motors. B and C are the two pulleys, the circumferential speed of which is varied by changing the speed of the motors m, m'. The endless rope D is in this case not attached to the car, but runs around a pulley E carried on the bottom of the counterweight W and around the pulley Y carried on the under end of the rope-tightening device N. The ropes L are attached to the car, and after passing over sheave M are attached to the counterweight. The ropes F also attach to the top of the counterweight, and after passing over sheave G and through cross-bar 3, are fastened to cross-bar 4 of the tightening device. By drawing bar 4 down on the threaded rods, the ropes can be tightened to any desired degree. The speed of the motors is controlled from the car, and in making a trip they are not

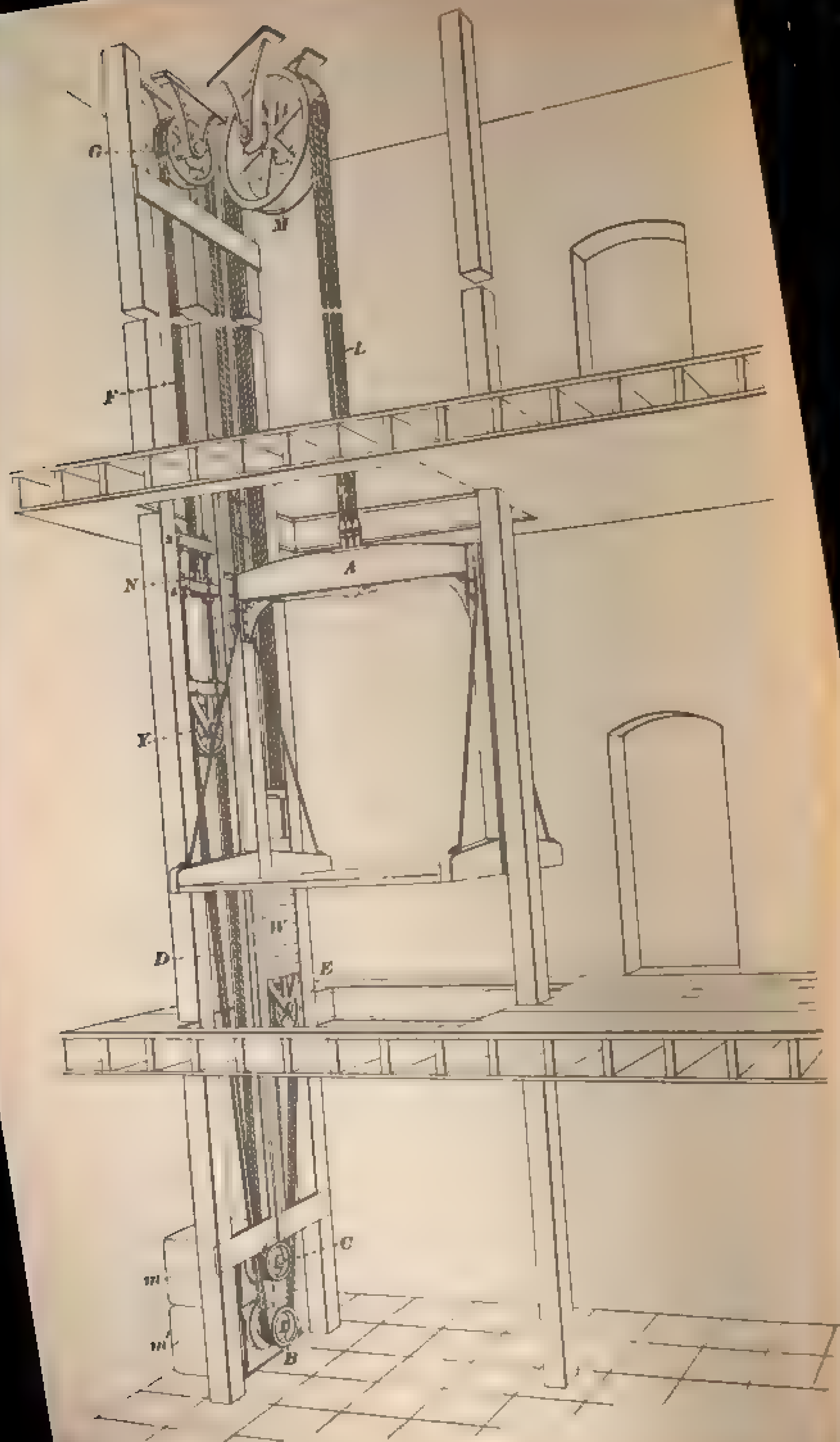


FIG. 54

stopped when the elevator stops at the various floors; they are merely made to run at the same speed by means of the car controller. While the car is ascending, pulley *B* runs faster than *C*, and in order to make it descend, all that is necessary is to make *C* run faster than *B*. The variations in speed are readily accomplished by varying the field strength of the motors. The controller is arranged so that when the handle occupies the central position, the speed of both motors is alike and the car is stationary, and when moved to either side of the center, the speed of either one or other of the motors is changed. A small auxiliary-operating handle is also provided in connection with the main handle, so that by pulling up on it the operator can stop both motors when the elevator is not in use.

ELEVATORS.

(PART 3.)

HYDRAULIC ELEVATORS.

INTRODUCTION.

1. Hydraulic elevators are still considered by the majority of engineers as being the most suitable for large passenger-service plants with their high lifts and great speeds, although the electric elevator has since its advent become a powerful competitor. The hydraulic elevator is intrinsically safe, reliable, smooth-acting, and under perfect control. It requires comparatively less care in operation than the electric elevator, the mechanism being very simple. The cost of maintenance is small, the wearing parts being few and easily and cheaply replaced.

On the other hand, the hydraulic elevator is cumbersome, requiring much space, especially—and this is the case in most large plants—where the water pressure available is not high enough for direct use in the elevator cylinders, so that the installation of steam pumps, reservoirs, or tanks, and the necessary piping becomes necessary, not mentioning a boiler plant, which we may assume, for the sake of the comparison, as being already in existence for other than the elevator service. Thus, the first cost is great compared with that of an electric elevator plant, which, in case the right current is already available, either from a central station or from an isolated lighting plant in the building, consists of

the elevator machine only, which may even be placed on top of the hoistway, and in case the current must be generated expressly for the elevator, of an additional steam-engine- or gas-engine-driven dynamo, but no cumbersome tanks or piping. The installation is thus simple and cheap, the space needed but small. There are advantages, then, in both systems, and which one to select depends on many circumstances which must be weighed against one another by the architect and owner, but not by the operating engineer, who should have no prejudice against the one or the other, but should be equally familiar with both.

PLUNGER ELEVATORS.

SERVICE.

2. The simplest kind of hydraulic elevator is the **direct-acting** or **plunger elevator.** It is also the oldest kind of hydraulic elevator and has been used for a long time, both for freight and passenger service, for short lifts. It has been until recently considered unsuitable for high lifts and high speeds, and is therefore found installed in great numbers as yet only for sidewalk lifts, slow freight elevators, and similar service. Lately, however, the possibility of using this type of elevators for greater lifts and speeds has been recognized, and it is safe to predict that they will be more frequently installed than before and for even the severest service.

CONSTRUCTION.

3. Fig. 1 shows a plunger elevator made by Morse, Williams & Co., of Philadelphia, Pennsylvania, for short lifts.

4. Motor.—The motor in this machine consists of a vertical cylinder *A* sunk into the ground below the bottom of the hoistway and a plunger *P*. The cylinder is closed at

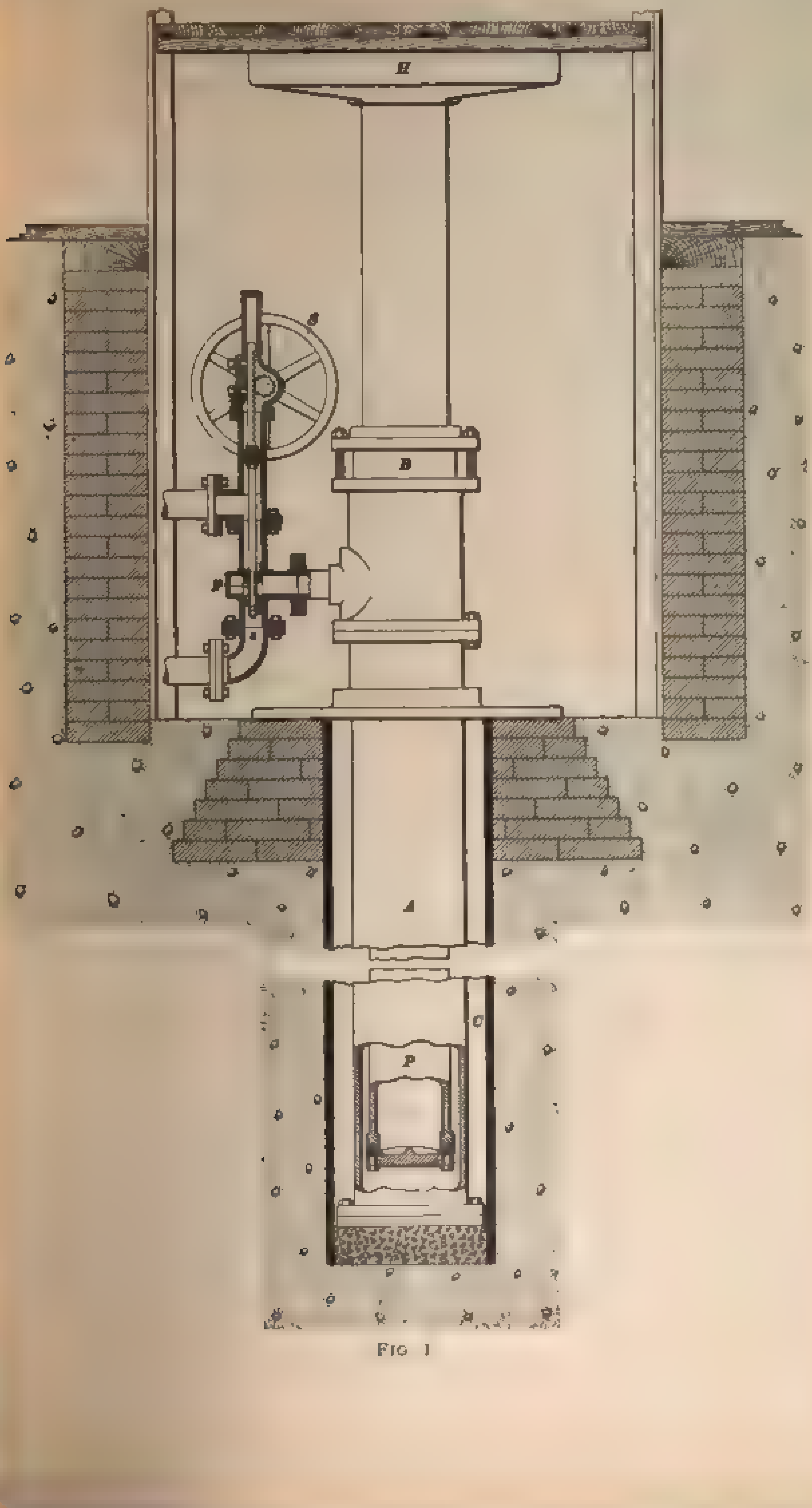


FIG. 1

the bottom and has an enlarged head above ground containing the stuffingbox *B* and an opening for the pipe through which the water under pressure enters the cylinder and is discharged from it. The cylinder must, of course, be sunk plumb. If the subsoil is soft earth, it is first necessary to sink a steel pipe *C*, called the **casing**, through which the earth is removed. When the subsoil is rock no casing is required, the hole for the cylinder being drilled.

For high lifts the cylinder is made up of sections. The Plunger Elevator Company, of Worcester, Massachusetts, use steel tubing, which they square up and thread in the lathe, connecting the sections by means of couplings. This insures a perfectly straight cylinder. Before burying in the ground the cylinder is tested and given a coat of preservative paint.

The plunger when required to be long is also made up of sections of steel tubing. Fig. 2 shows the special joint used by the company named above. The plunger is turned to uniform size and polished.

Fig. 2

5. Transmitting Devices.—As the car rests directly on top of the plunger, there are no transmitting devices, such as drums, ropes, and sheaves. The car is fastened to the plunger, which is provided with a head *H* for the purpose. The head shown in Fig. 1 is simply a cast-iron plate clamped to the plunger. This arrangement, while sufficient for unbalanced small elevators, would be dangerous for large counterbalanced ones, inasmuch as should the connection between the head and the plunger give way, the counterweights would jerk the car upwards against the overhead work. Great care is, therefore, taken in balanced elevators of this kind to make the aforesaid connection very rigid and reliable. The manner in which this is done by the Plunger Elevator Company is shown in Fig. 3.

The plunger has a flange formed on its upper end that fits into a corresponding recess of the head *H*. The latter, in turn, is securely bolted to the framework of the car platform. Besides this flange connection a second security

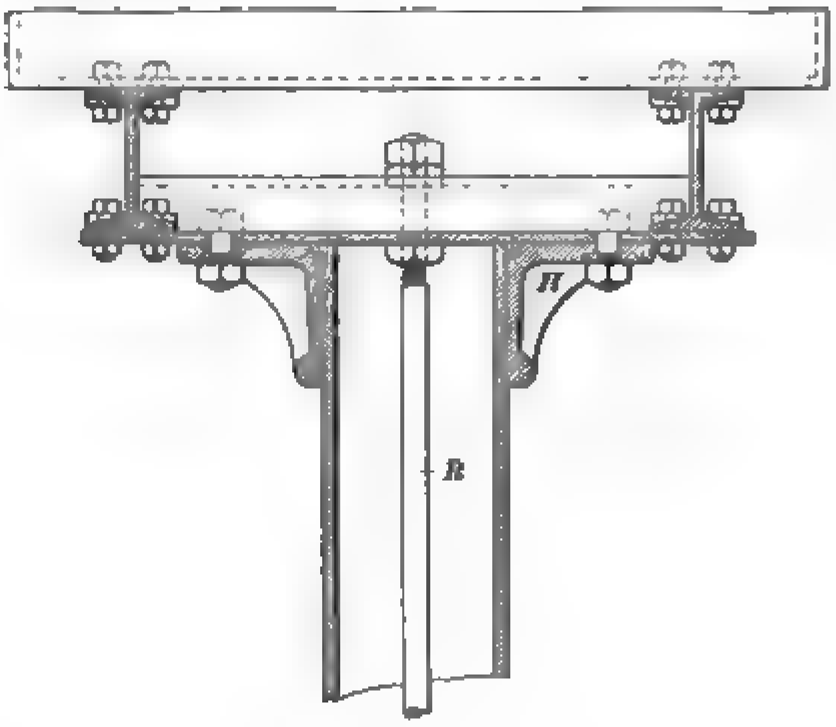


FIG. 3.

against the parting of the car and plunger is provided by a tie-rod *R* which runs all the way through the plunger, through the bottom of the same, and through the framework of the car platform. Instead of the rod *R* a loop of galvanized iron rope is often used for the same purpose.

6. Counterbalancing.—Low-lift plunger elevators are generally not counterbalanced at all. High-lift elevators are counterbalanced, but not overbalanced, since the power acts only on the up stroke of the plunger. Enough of the weight of the car and plunger is left unbalanced to secure the descent of the car at the proper speed when empty. The upward pressure of the water on the plunger gradually diminishes as the plunger goes up by an amount corresponding to the increasing height of the water that displaces the plunger. To equalize this change of pressure, the counterweights are suspended from cables of such size that the weight per each foot of their length passing over

the overhead sheaves will be equal to the weight of 1 foot in height of water displacing the plunger.

7. Controlling Devices.—The controlling devices consist simply of a balanced three-way water valve operated by a simple shipper rope, or a shipper rope in connection with some more elaborate operating device. The simple shipper rope is generally used with the smaller machines, while an operating device of more elaborate form is used for the larger machines.

The valve in a hydraulic elevator constitutes the only controlling device, being power control and brake at the same time. As a power control it shuts off the power at the will of the operator; as a brake it is so designed as to shut off the water gradually by throttling. This object is most easily attained by a piston valve, which type of valve is used exclusively. Thus, while there is no brake in the common meaning of the word in hydraulic elevators, it is, nevertheless, there as in any other elevator, but in a different form.

This identity of power control and brake is one of the intrinsically valuable features of the hydraulic elevator, since by opening the water passages more or less, the speed of the car can be regulated to a nicety and in harmony with the load it carries, which feature is not easily attained, if attained at all, in any other kind of elevator. Generally the valve is proportioned by the installators so that when fully open it will give the empty car the maximum speed permissible; but by the use of stops the valve throw can be adjusted to any car speed. Such stops are generally in the shape of knobs or buttons clamped to

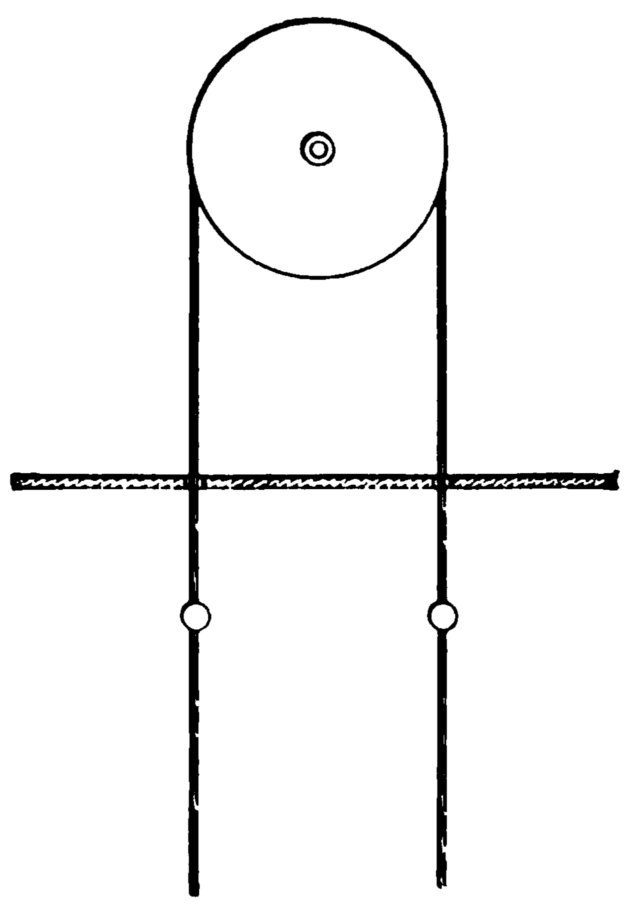


FIG. 1.

the shipper rope and striking against some fixed projection, as shown in Fig. 4. These stops are called **back-stop buttons.**

8. The valve used on the Morse, Williams & Co.'s elevator is shown in section in Fig. 1. A peculiar feature of this valve is the shape of the piston *p*, which is seen to be wedge-shaped, in consequence of which the water passes to and from the machine gradually and without shock. The operation of the valve will be readily understood from the drawing; on shifting it one way by means of the shipper rope passing over the sheave *S*, water flows from the *supply* into the *machine* and exerts a pressure on the plunger, lifting it and the car. By shifting the valve in the opposite direction, communication is established between the *machine* and the *discharge*, and the elevator descends. In the intermediate position, the valve shuts off all communication of the machine with the supply and discharge and the elevator is at rest, the plunger being supported on a column of water confined in the cylinder.

9. In larger machines the controlling valve is preferably moved by a motor piston, which is operated by a **pilot valve.** The pilot valve is in turn controlled by the shipper rope from the car. The arrangements of pilot valves and main valves differ in different installations, but are easily understood in every case by inspection. We shall encounter the pilot valve again in connection with piston elevators, when descriptions and drawings of several types will be given and their purpose explained.

10. Safety Devices.—The plunger elevator is the safest elevator built. The ordinary knobs or buttons used on the shipper rope as limit stops are the only motor safeties provided, and even should the limit stop fail to operate the valve at the top of the run, the counterweight would reach the ground and the car stop; should the limit stop fail to operate at the bottom of the run, the car would simply come to rest on the cylinder. In order to avoid damaging the cylinder head in case this should happen, buffer springs are

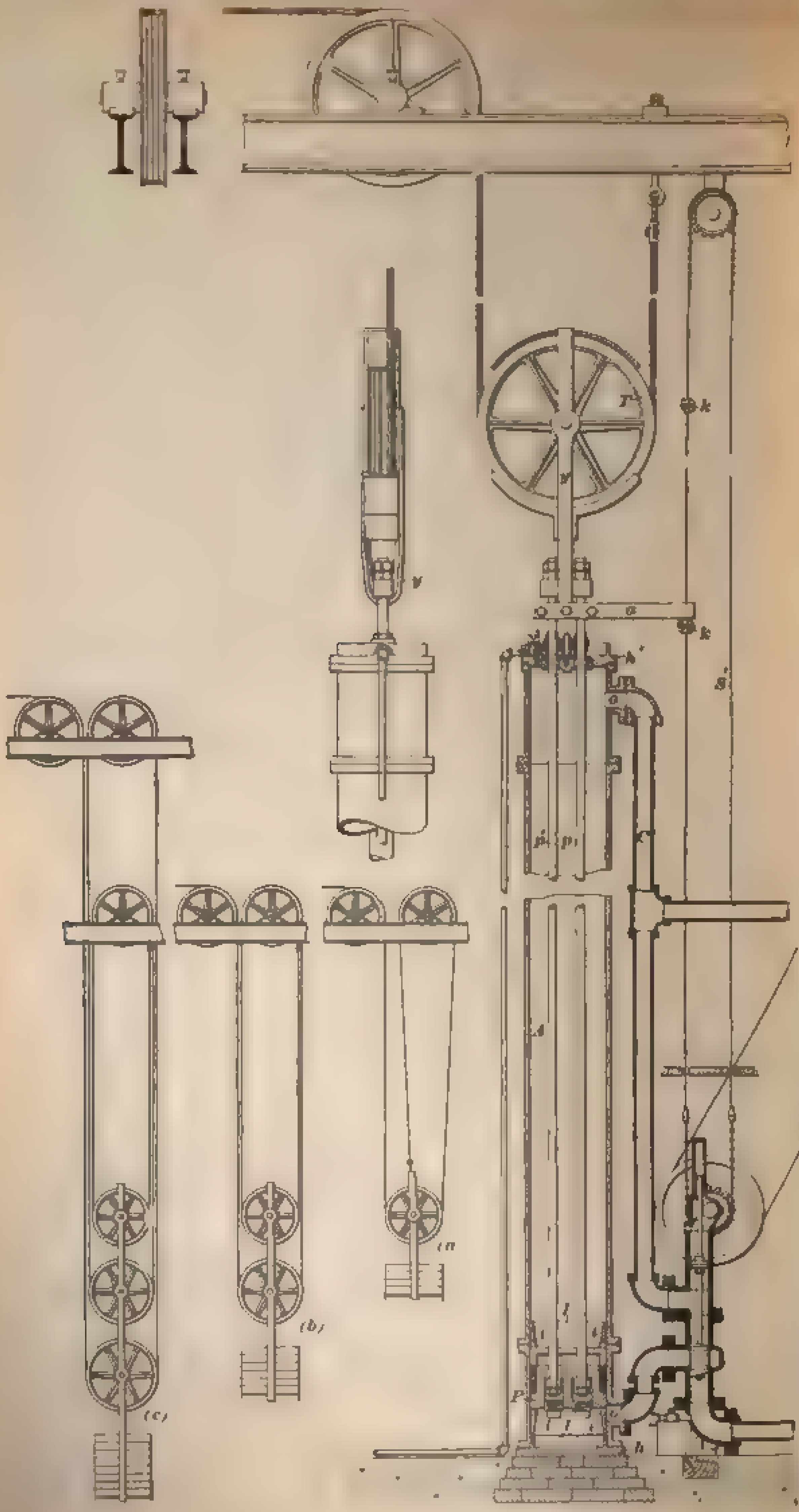


FIG. 5

often placed on top of the cylinder head, especially when the speed of the elevator is considerable. Car safeties, which are essential on all other elevators, are not needed in plunger elevators, for the car cannot fall, since the plunger always rests on a column of water that is driven out through comparatively small openings; it may, however, in case the valve should fail to operate, attain a speed that would be undesirably great, though not dangerous. To provide against this, the simple expedient of putting in the discharge pipe a throttle valve controlled by the pressure corresponding to the velocity of the exhaust is resorted to when necessary. The car cannot be violently pulled against the overhead work by the counterweight as long as the connection between the car and the plunger is secure, which security is easy of attainment.

PISTON ELEVATORS.

ADVANTAGES.

11. While the plunger elevator treated in the previous articles is simplicity itself, it has some disadvantages. The hydraulic cylinder and plunger must have a length equal to the lift, and for each trip of the car a volume of water is used equal to the area of the plunger multiplied by the lift. In the piston elevator, by introducing multiplying sheaves the hydraulic cylinder can be made considerably shorter, and thus the volume of water used for each lift reduced accordingly. There are two types of piston elevators in general use. In one the cylinder is *vertical* and in the other *horizontal.*

VERTICAL HYDRAULIC PISTON ELEVATORS.

12. The vertical type is considered better than the horizontal type, and is always installed when circumstances will permit, chiefly for the reason that generally headroom is more available than floor space. Fig. 5 is a section through

the cylinder, piston, and valve of a simple machine of this kind, as built by Morse, Williams & Co., of Philadelphia, Pennsylvania

13. Motor.—Following up the various parts, we have as the motor a cylinder *A* and piston *P*, the former consisting of a number of cast iron flanged sections bored and faced true and bolted together at their flanges; a bottom head *h* and a top head *h'*, which latter contains the stuffingboxes for the piston rods *p* and *p'*. The cylinder has two openings *o* and *o'*, at the top and bottom, respectively.

14. Transmitting Devices.—The transmitting devices consist of wire ropes running over sheaves, one or more of which are carried in a yoke *y* attached to the piston rods, while the others are supported in bearings on overhead beams. The main figure shows but one **traveling sheave** *T*; the car in this case moves twice as fast as the piston, and the elevator is said to be geared in the **ratio** 2 : 1. Fig. 5 (*a*), (*b*), and (*c*) shows the arrangement of sheaves for the ratios 3 : 1, 4 : 1, and 6 : 1, respectively.

15. Counterbalancing.—As we shall see presently, matters are arranged in most vertical elevators so that the cylinder is always full of water. This gives rise to an advantage in counterbalancing. The piston is always carried on a solid column of water and thus forms a counterweight that will come to rest at the moment when the power is cut off, that is, the flow of water stopped; contrary to a free counterweight, it will thus not produce a tendency to teeter the car up and down by its momentum when the power is suddenly cut off. The counterweights in these elevators are, therefore, preferably placed wholly or at least partly on the piston or piston rods, as shown in Fig. 5 (*a*), (*b*), and (*c*). As the power acts only on one side of the piston, the counterweights must be less than the car weight by an amount sufficient to make the car descend at the proper speed when empty.

16. Controlling Device.—The controlling device consists of a balanced three-way valve operated by a shipper rope in the usual manner, the rope being provided with back-stop buttons. The action of the motor under its control is as follows: The space of the cylinder above the piston is always filled with water under pressure, the supply pipe being connected with this space directly through the **circulating pipe** *C*. The other end of the circulating pipe is connected with the space of the valve chamber between the two valve pistons. If the valve pistons be moved downwards, so as to bring the upper valve chamber and thus the space of the cylinder above the piston into communication with the space below the piston, there will be the same water pressure on both sides of the piston. The car, being heavier than the piston with the counterweights, will cause the latter to ascend while it is itself descending, and will force the water from above the piston through the circulating pipe into the space under the piston. For the ascent of the car the valve pistons are raised so as to put the space of the cylinder below the piston into communication with the discharge pipe; there is then pressure only on top of the piston, and the same descends, raising up the car. In the position shown in Fig. 5, the valve closes the space below the piston against both the supply and the discharge, so that the piston is held between the water pressure from above and a confined water column from below.

The object of making the water circulate from the top to the bottom of the piston is primarily to make the effective pressure on the piston the same at all points of the stroke, which otherwise would not be the case. Imagine that the cylinder was open at the top and bottom and the piston at the top of its travel, and that water be poured on to the piston from above; then the latter would descend under the influence of the weight of the column of water above the piston, which would be nothing at first, but would gradually increase towards a weight equivalent to the total contents of the cylinder. Imagine, now, that the space below the piston is filled with water, the piston again being at the top; then

the column of water underneath it will exert a suction on the piston corresponding to the height of that column, as long as the column is not higher than 34 feet, which suction will gradually decrease to nothing as the piston descends. Thus by having the space below the piston filled with water the same net force is exerted on the piston at all points; for, while the pressure of the water above it increases, the suction of the water below it decreases at the same rate. In concise technical terms, then, the object of the circulation of the water from the top to the bottom of the piston is to balance the head of the water above the piston.

17. Safety Devices.—The safety devices consist of the usual *car safeties* used for suspended cars and *motor safeties*. Limit stops take the shape of knobs or buttons *k*, *k*, Fig. 5, on an endless rope *S*, which are operated by a projecting arm *a* on the piston rod. The top and bottom heads would of course stop the travel of the piston either way, but it would not be safe to intrust them with that duty, as breakage may result by the piston striking them. The latter should not, therefore, ordinarily travel so far as to strike the heads. There being a possibility, however, that this might occur through a failure of the valve to operate, the piston is provided with an **apron** *l* on each side; each apron has a number of holes *i*, *i* through it and partially closes the ports *e* or *e*, and thus reduces the speed of the piston before it reaches the heads. The holes *i*, *i* allow the water to enter on the return stroke.

18. It can easily be understood that every elevator should be started and stopped gradually to avoid shocks, and that there always exists the danger of overthrowing the controlling device beyond the neutral point.

Referring to Fig. 5, it will be understood that when the piston is going down the car is ascending, and if the valve is suddenly closed, the flow of the water from the space below the piston through the discharge pipe is suddenly stopped. The momentum of the piston and car will tend, however, to

continue the motion, resulting in a thud of the piston against the column of water thus confined. To avoid this **water ram,** as it is called, it is good practice to interpose in the discharge pipe between the cylinder and valve a **relief valve** *r*, as shown in Fig. 6, which is a drawing of an **Otis vertical elevator** of much the same design—with the exception of some details, to which we shall refer below—as that shown in Fig. 5. The danger of producing a shock by the careless handling of the operating device on the down trip of the car is not so great, inasmuch as the column of water above the piston is not confined in the cylinder on closing the valve, being always in communication with the supply pipe and through it with the pressure tank and its air cushion. A relief valve for the down trip is, therefore, deemed superfluous.

19. Pilot Valves.—For high-speed hydraulic elevators (600 feet per minute and more), the insertion of the relief valve is not sufficient to guard against shocks, it being extremely difficult to start and stop gradually by operating the main valves directly; nor is it possible to regulate the speed readily by opening the valve more or less, so that one of the most valuable features of the hydraulic elevator is curtailed. This has led to the introduction of the **auxiliary,** or **pilot, valve,** already referred to in Art. **9.** Such a valve as built by the Otis Elevator Company is shown in Fig. 7, of which the following is a brief description:

Contrary to the direct-operated valves shown in Figs. 5 and 6, the main valve V, Fig. 7, composed of the pistons v and v', is not balanced, but the upper piston v has a larger area than the lower double one v'; the valve is, therefore, also called a **differential valve,** there being always a pressure against the under side of the upper piston v depending on the difference between the areas of the pistons v and v'. On a bracket B fixed to the main valve casing is supported the auxiliary, or pilot, valve W, which is simply a piston valve of small dimensions; the casing of this valve has an inlet w connected with the circulating, or supply, pipe and

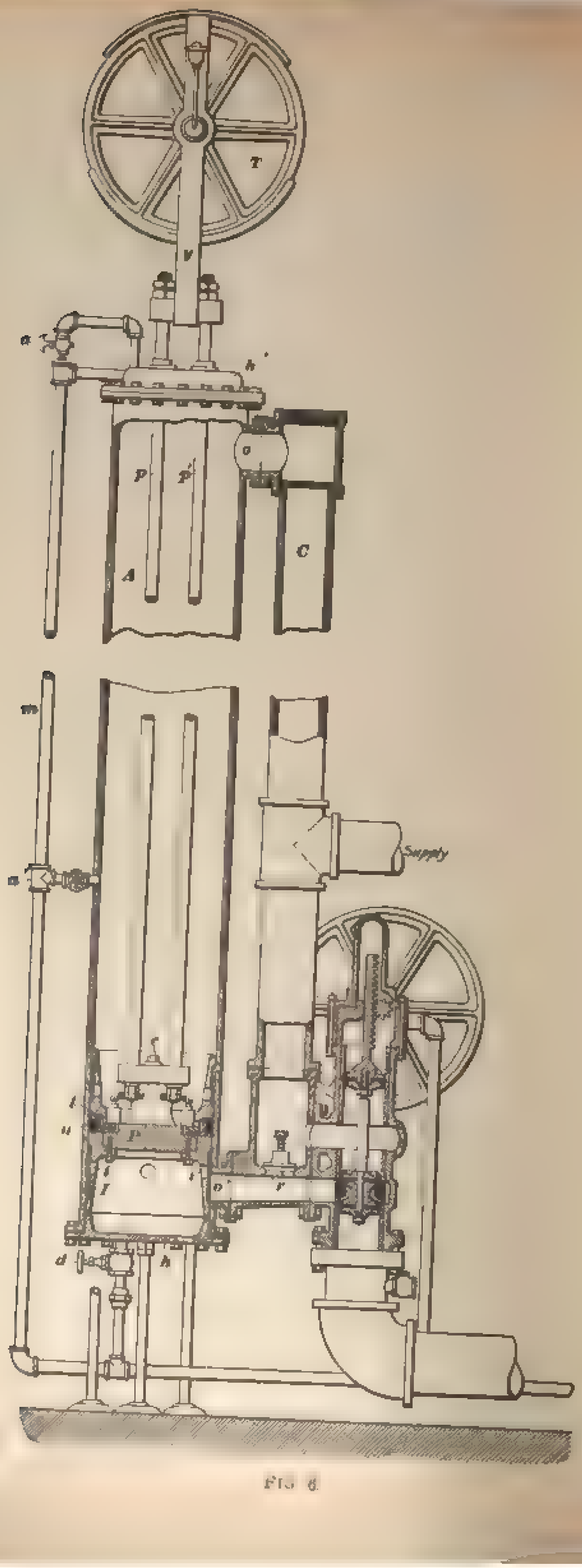


FIG. 6.

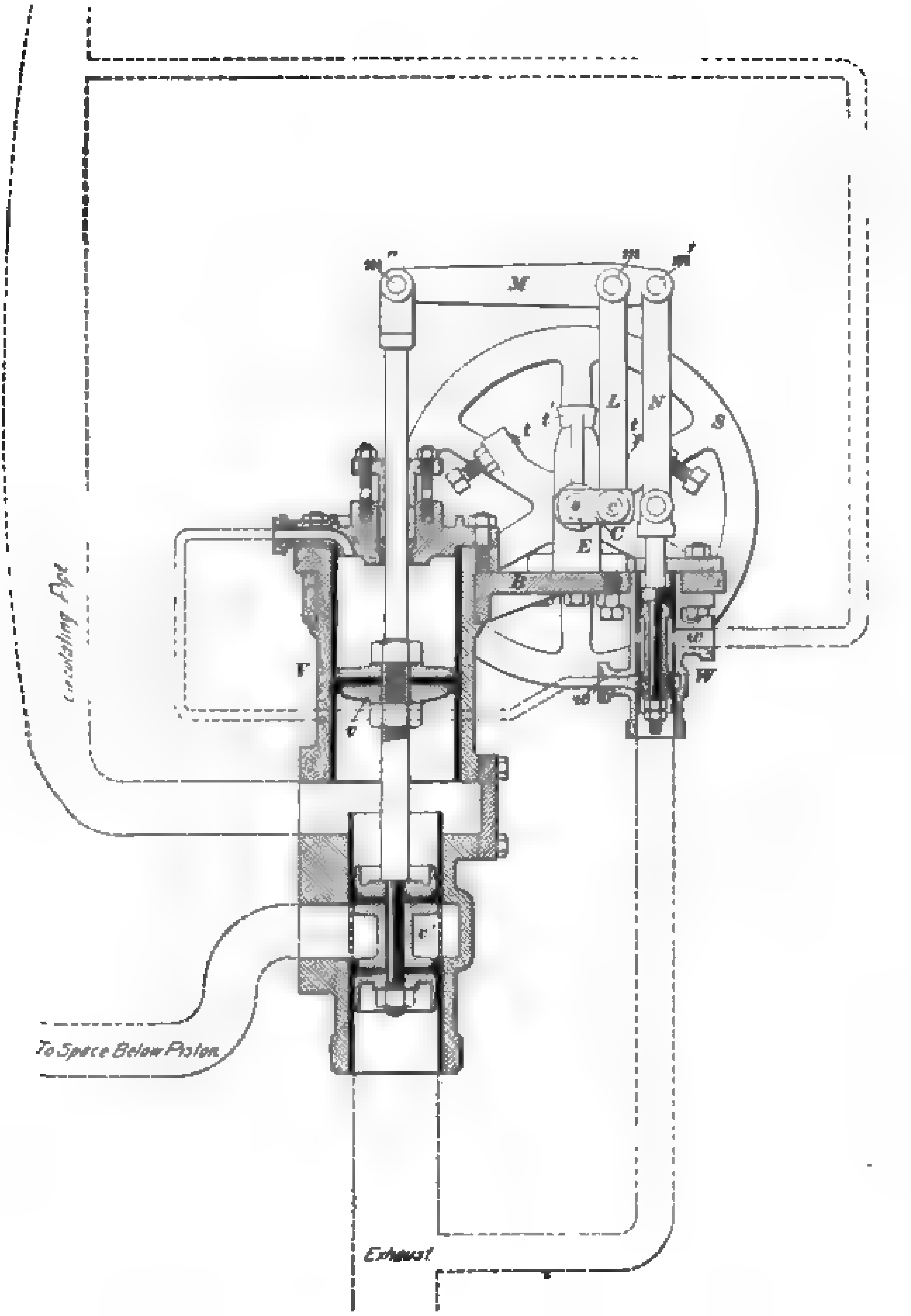


FIG. 7.

an outlet w' connected by a pipe to the space above the upper piston of the main valve, as shown. In the position of the two valves shown in the illustration, the communication between them is shut off, the pilot-valve piston covering the outlet port. The upper space of the main valve is filled with water wholly confined, so that the tendency for upward motion of the piston v is checked in a position where the lower piston cuts off the circulation of the water, when, as we know, the elevator is at rest. By lowering the pilot valve, communication is established between the supply, or circulating, pipe and the space of the main valve above the piston v, which presents its whole area to the incoming water; as the upward pressure below it is less, owing to the difference between its area and the area of the lower piston v', it will descend with the effect of allowing a circulation of water from the top to the bottom of the cylinder, so that the car descends. If, now, the pilot valve be brought back into the position shown in Fig. 7 (the main valve being in its lowest position for the down trip of the car), it would check any farther downward motion of the main valve and the same would thus remain set for the down trip. Again, if the pilot valve were raised beyond the position shown in Fig. 7 (the main valve still being in its lowest position), the space above the piston v would be connected with the exhaust and the main valve would ascend and keep on ascending to the neutral position (elevator at rest) and beyond it (elevator descending), unless the pilot valve be brought back to the neutral point.

Thus, if no provision be made further than described, it would be necessary, in order to stop the car during a downward trip, to throw the pilot-valve operating device completely over, to wait until the elevator came to a stop, and then to throw the device into the central (neutral) position. The same complicated operation would be required for the upward trip.

20. To avoid the complicated operation mentioned in Art. **19**, the two valves are so connected by a system of

linkwork that the pilot valve closes automatically without affecting the operating device in the car (shipper rope, lever, or hand wheel) when the main valve reaches its extreme upper or lower positions. This is brought about in the following manner: The shipper sheave *S* is mounted on the bracket *B*, its shaft *s* carrying a crank *C*, the crankpin *c* of which is connected to a double-armed lever *M* by a link *L* and a pin *m*. To the right of the pin *m* is another pin *m'* that serves as a pivot for a link *N*, which is connected at the other end to the stem of the auxiliary valve. A third pin *m''*, to the left of the pin *m*, connects the lever *M* with the main-valve stem. Stops *t*, *t*, *t'* on the shipper sheave and its stationary bearing, respectively, limit the motion of the crank *C*.

The operation is as follows: Starting, as before, from the position of the valves shown in Fig. 7, the piston *v* is held stationary between the water pressure from below and the confined water above, so that the pin *m''* forms the pivot of the lever *M* when we move the shipper sheave to the right. The crank *C* then pulls down the lever and with it the pin *m'*, link *N*, and the pilot-valve stem, thus lowering the pilot valve to the position in which it admits water into the main valve, which then moves downwards. As soon, however, as it commences to move, it raises up the pilot valve, the crankpin *c*, as well as the link *L* and the pin *m* being now stationary, which latter then serves as the pivot for the lever *M*. The leverage is so proportioned that by the time the main valve has reached its lowest position the pilot valve will be closed, that is, it will have returned to the position shown in Fig. 7, checking further motion of the main valve, the crank *C*, however, remaining in its lowest position. If it is now desired to stop the car during its down trip, the sheave, and with it the crank, is brought back to the neutral position. The pin *m''* being, now, once more the pivot for the lever *M*, the pilot valve is raised above its neutral position, the main valve rises, and by the time it has risen far enough to shut off circulation of the water it has dragged the pilot valve back to its neutral

position. All parts are now again placed as shown in Fig. 7 and the cycle may be repeated.

21. Though it takes many words to describe it, the operation of this valve is very simple and reliable. The operator may with impunity throw the operating device quickly from its neutral position to the right or the left, that is, for "up" or "down," without affecting the gradual, measured motion of the main valve, which is the purpose of the pilot valve. Moreover, it will be understood that the pilot valve allows a perfect regulation of the speed of the car. For by throwing the operating wheel or lever on the car over only part of its full swing, the pilot valve will make only part of its travel and, consequently, will be brought back to its neutral position by the action of the main valve before the latter has completed its full stroke, thus leaving the main valve but partly open, whereby the flow of the water is throttled.

22. Independent Top and Bottom Stop-Valve.—In connection with a pilot valve, the ordinary kind of limit stop shown in Fig. 5 operating the valve directly cannot be used, for the piston or car will still be moving, while the quick move of the pilot valve has long been completed. It becomes necessary, then, to introduce an independent valve for stopping the car at its limits of travel. Such a valve is shown in Fig. 8 at *Q*, and its construction and operation are as follows: Into the passage leading from the space below the elevator piston to the exhaust, a cylindrical shell *q* having three passages is inserted, of which the upper passage leads to the relief valve (see Art. **18**). Either of the two passages *t* and *t'* may be closed by the rotary valve, shown to an enlarged scale in Fig. 9, which consists of a spindle *s* passing through stuffingboxes of the valve casing and carrying a valve body *z* composed of a sleeve and flanges fitting the inside of the shell *q*. The flanges of the valve body are notched out to receive the valve proper *w*, which fits with considerable play in the notches, as shown

in Fig. 9. The valve spindle carries on the outside of the casing a gear-wheel *g*, Fig. 8, actuated by a weight *W* that tends to keep the valve in the neutral position shown in Fig. 8. The gear *g* meshes with a smaller gear attached

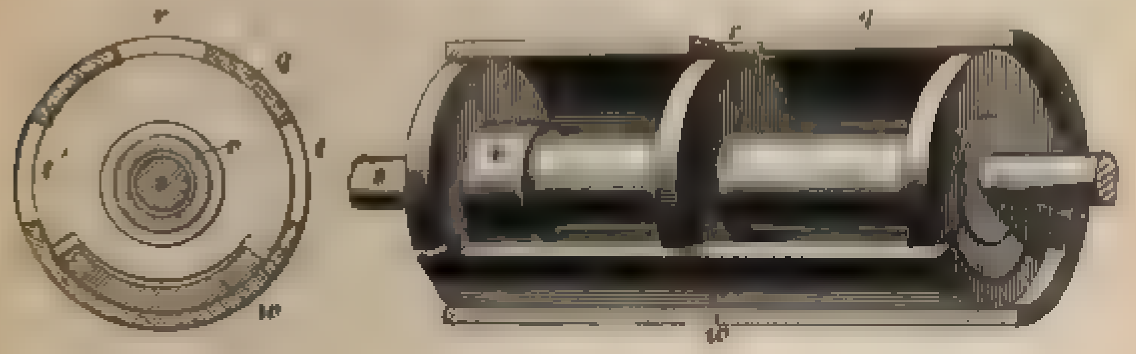


FIG. 9.

to the shaft of a rope sheave *S*, which is actuated by an endless rope passing over an idler above and carrying the usual stop buttons. Now, when the piston nears its lowest position, the arm *a* on the piston rod strikes the lower stop button; the sheave *S* swings right-handed and the valve *w* turns left-handed, covering up the right-hand port or passage *t*, thus shutting off gradually the communication of the cylinder with the exhaust and stopping any farther downward motion of the piston, even if the operator has neglected to move the pilot valve.

In order that the elevator may start again upon reversing the pilot valve, the valve *w* of the rotary stop-valve has a certain play, as already stated. Thus, imagine the piston in its lowest position and the valve *w* covering up the port *t*; it will then be pressed against its seat (the shell *q*) as long as the main valve uncovers the exhaust or is in the middle position, by reason of the pressure above the piston. But as soon as the main valve is reversed, so as to open communication between the spaces above and below the piston through the circulating pipe, there will be an excess of pressure against the outside of the valve *w* of the rotary valve, due to the unbalanced weight of the car. The valve *w* will then be lifted off its seat and will allow water to pass below the piston, which then commences to rise. Presently, the arm *a* will leave the lower stop button and the rotary valve

will swing back to its neutral position by virtue of the weight W, Fig. 8. Similar action takes place at the extreme upper position of the piston.

23. Throttle.—A difference will be noticed in the construction of the main valve between that shown in Fig. 7 and that shown in Fig. 8, there being interposed in the latter case a metal sleeve between the upper single piston and the lower double one. This sleeve, which is called the **throttle** and is designated by *T*, Fig. 8, is fastened to the valve rod, or stem, and in its neutral position shuts off the supply from the space between the valve pistons. Otherwise, the connections and passages are the same, the supply being in constant communication—except when shut off by the throttle—with the circulating pipe by two branch passages leading from the annular chamber around the throttle to the circulating pipe. In order to show this clearly, a horizontal section through the middle of the throttle and its casing is given to an enlarged scale in Fig. 10 (*a*).

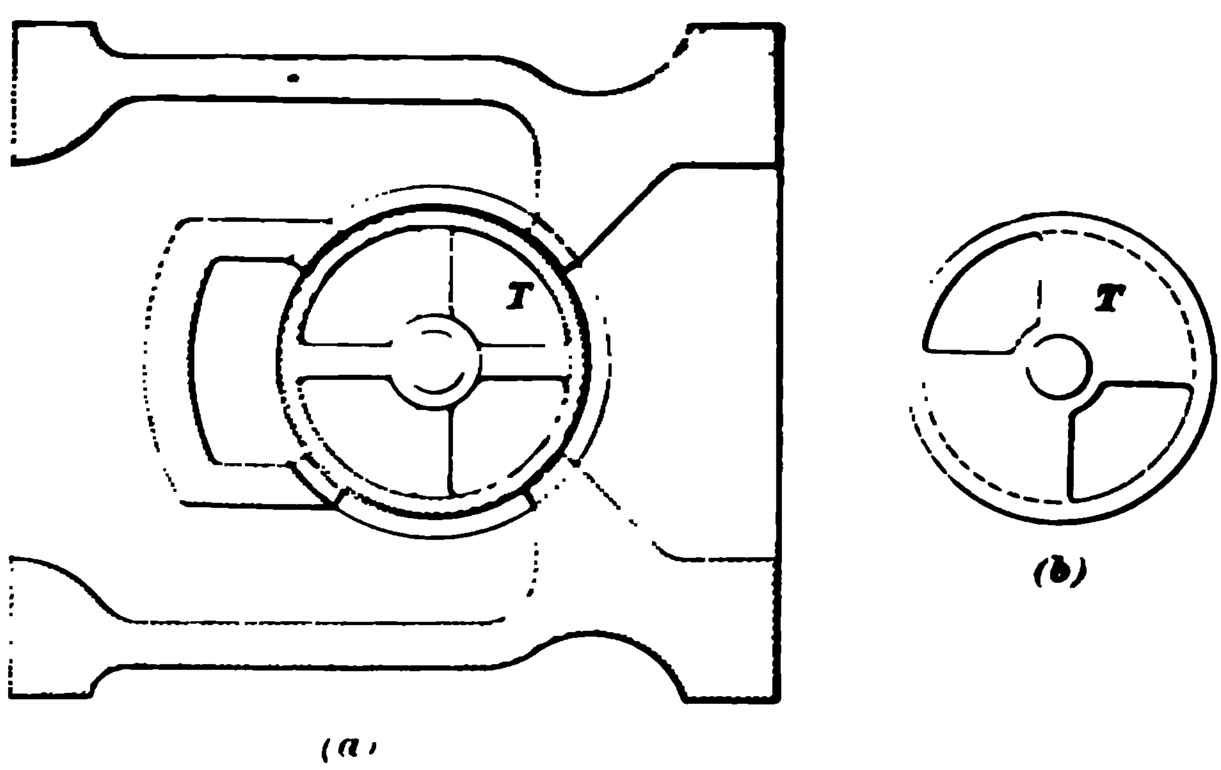


Fig. 10.

The purpose of the throttle is a threefold one. (1) It serves, if carefully adjusted, to deaden the noise occasioned by the circulating water. (2) It serves as a brake while descending, in case of an extra load on the car, preventing

it from attaining undue speed. This is accomplished by the top of the throttle sleeve being partly closed, as shown by the plan view given in Fig 10 (*b*), thus allowing only a small amount of water to pass through, that is, throttling it. (3) If any pipe or connection between the supply and valve should break, the water cannot back up from the circulating pipe out through the supply port faster than it can leak around the outside of the throttle.

24. The throttle is but loosely fitted to its seat, or lining, so that there is always some leakage around it, otherwise the elevator could not be started from its position of rest, since there would be no outlet for the water between the large and small piston of the differential valve while descending, and to the inlet while ascending. This leakage is sometimes solely depended on to give the differential valve the initial start, but oftener a by-pass pipe *x*, Fig. 8, leads from the supply chamber of the pilot valve to the space under the upper piston of the differential or main valve. This by-pass pipe is provided with a globe valve, by means of which the rapidity of the initial start can be regulated.

25. Double-Power Vertical Hydraulic Elevator.—In modern office buildings safes and other heavy furniture are frequently moved about, and one of the elevators in such a building is, therefore, generally designed for a much heavier load than the others. The necessary power is obtained from an extra-high-pressure tank. In order, however, that this elevator may be used for ordinary loads as well, with no greater expense than the others, a special valve is used that permits it to be used at will either with the ordinary low pressure or with the high pressure. Such a valve, built by the Otis Elevator Company, is shown in Fig. 11. The upper valve *v* is, in this case, a piston valve straddling in its neutral and lowest position the high-pressure port. The throttle *T* has ports *t*, *t*. When the valve stem is moved down, the water circulates as in the ordinary hydraulic machine and the car descends. When the valve stem is moved up, the discharge

[illegible] and as the low-pres- [illegible] cylinder through [illegible] pipe it raises the car to [illegible] valve stem is raised still [illegible] high-pressure inlet *r*, and [illegible] high-pressure water into the [illegible] ports and the circula- [illegible] full benefit of the high [illegible] valves both the low- [illegible] connected with the circulating [illegible] water would flow from [illegible] low-pressure tank, were it not [illegible] in the low-pressure supply pipe. [illegible]

26. Non-Circulating Systems.—In the vertical-piston [illegible] the distinguishing feature was [illegible] the water from above the piston to the [illegible] the ascent of the car. As we have [illegible] Art. **16**, the principal object of this arrangement [illegible] of the head of the water above the piston. [illegible] advantages in counterbalancing were [illegible] Art. **15**.

It is [illegible] that a ratio of 6 : 1 is the [illegible]. In certain designs, however, [illegible] above this value for the purpose of making the cylinder very small. Now, since the head of the water becomes less and less the shorter the cylinder [illegible] necessary to balance it when the ratio is very [illegible] for instance. In such cases the circulating pipe is dispensed with; the water then enters and leaves one side of the piston only and one end of the cylinder is left open to the atmosphere. Fig. 12 shows an elevator of this kind made by The Whittier Machine Company, of Boston. There are quite a number of these machines in operation. The ratio of the particular machine illustrated is 10 : 1, there being a set of five fixed and five traveling sheaves on each side of the cylinder;

from each of the two sets a rope passes to an overhead sheave and thence to the car. The fixed sheaves are arranged below the traveling sheaves, the latter being attached to a crosshead carried on the piston rods and guided on rails *R*, *R*. The piston moves *up* for the ascent of the car and *down* for the descent, so that the piston rods are in compression. Moreover, the piston moving in the same direction as the car cannot, as in the case of the previously described vertical machines, be utilized as a counterweight, but must itself be counterbalanced, which is done in the manner shown in the illustration, *W*, *W* being the weights. The controlling valve is much of the same construction as that shown in Fig. 5.

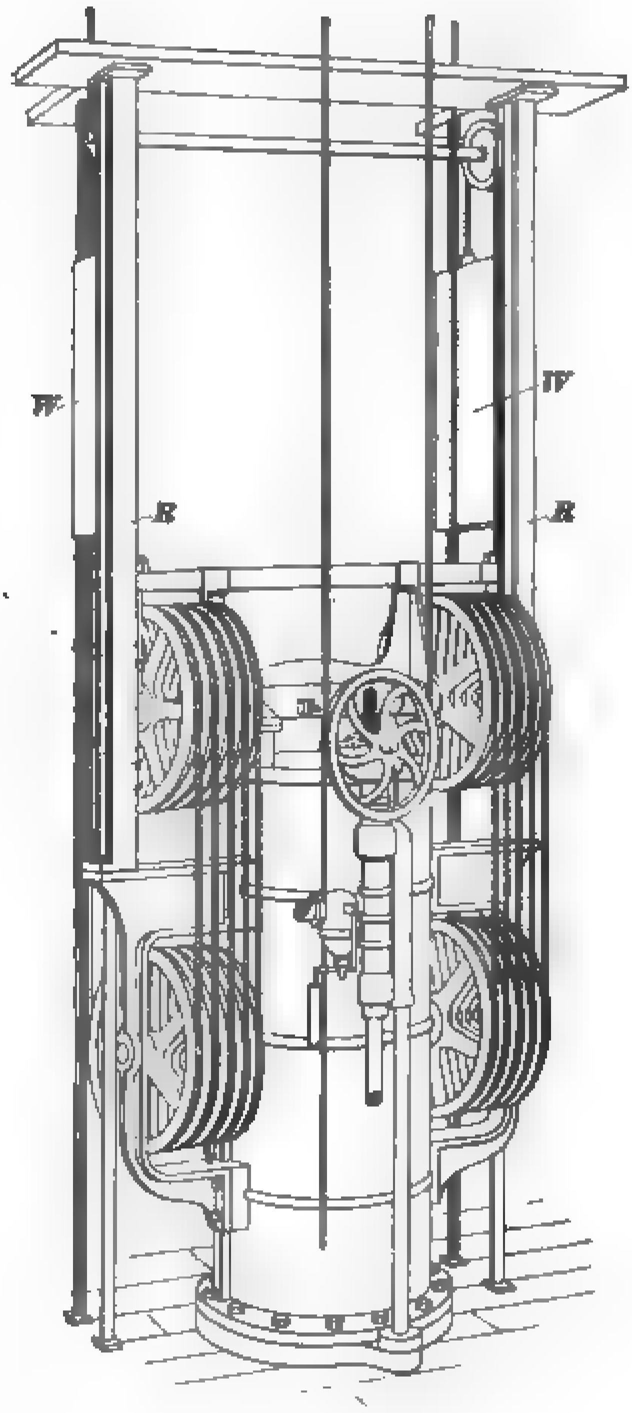


FIG. 12.

27. While in high-ratio vertical elevators of the kind shown in Fig. 12 the circulation of water is dispensed with, owing to the small head of the water, it becomes entirely dispensable when the cylinder is placed horizontally. All horizontal hydraulic piston elevators are, therefore, based on the non-circulating system

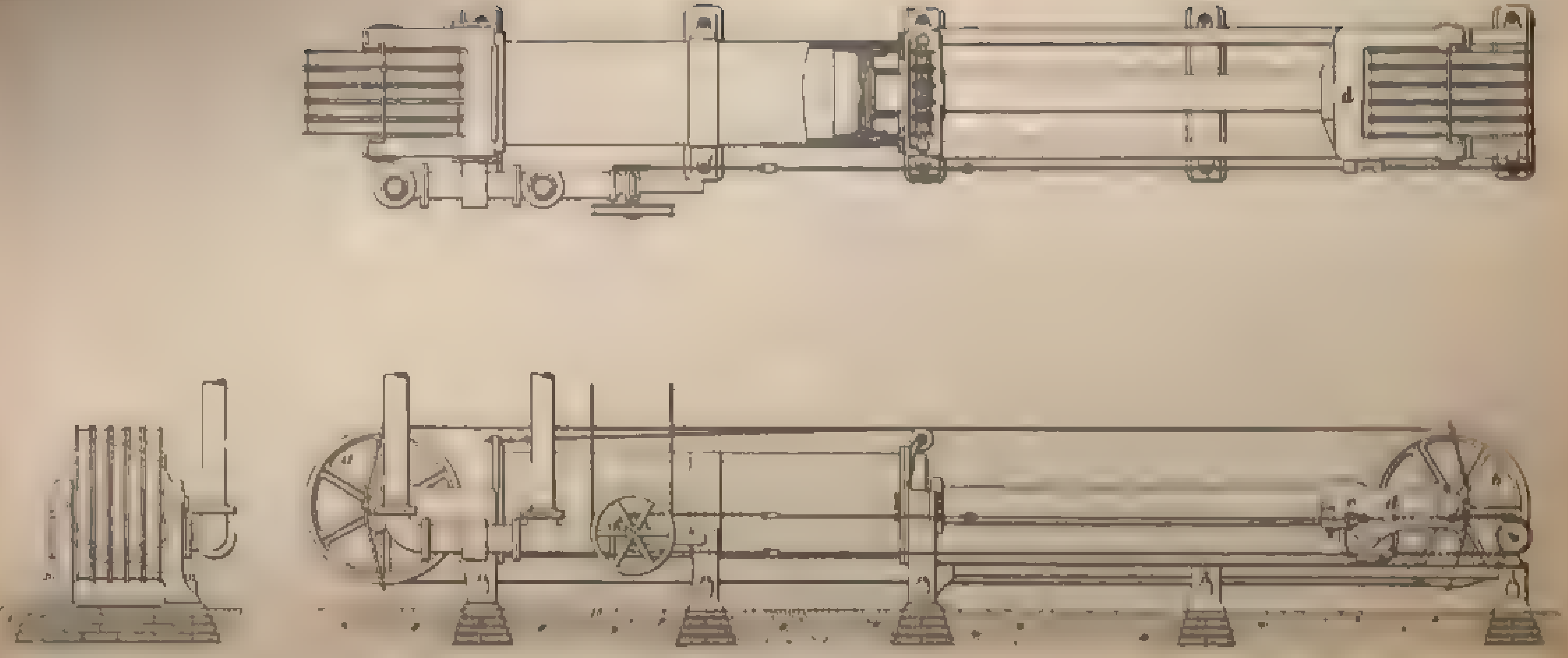


FIG. 13

HORIZONTAL HYDRAULIC PISTON ELEVATORS.

28. Advantages.—Although the floor space occupied by a vertical elevator cylinder is comparatively small, this floor space is required on each floor of the building, and where there are a number of elevators, the aggregate necessary space amounts to more than can in many instances be conveniently spared. Moreover, it becomes necessary, in case of a battery of elevators, to provide a separate well for the cylinders. Again, the long, upright cylinders so placed in a comparatively narrow well are inaccessible for the greater portion of their length. For these reasons preference is given to the horizontal type of elevator when there is sufficient floor space more available in the basement of the building than on the floors above. But under the most favorable conditions, floor space, even in the basement, is always limited, and it is desirable, therefore, to make the cylinders short, which necessitates a high ratio of the transmitting devices. This is generally chosen as 10 : 1. The sheaves in these machines are arranged either so as to put the piston rod in compression or so as to put them in tension.

29. Compression Type.—A simple machine of the compression type, built by Morse, Williams & Co., is shown in Fig. 13. The fixed sheaves are placed at the rear end of the cylinder and the hoisting rope is carried above and below the cylinder from the fixed sheaves *a* to the traveling sheaves *b* back and forth and is finally led off from the former to the car. The drawing calls for but little explanation. The controlling device consists of the three-way valve illustrated in Fig. 5; the motor safeties are limit-stop buttons carried on an endless chain or rope and actuated at the extreme positions of the piston by an arm or projection *c* on the crosshead *d*. The endless chain runs over a sprocket wheel fastened to the shipper-sheave shaft.

30. Tension Type.—The general arrangement of the tension type of horizontal hydraulic machines is shown in Fig. 14. Both the fixed and the traveling sheaves are

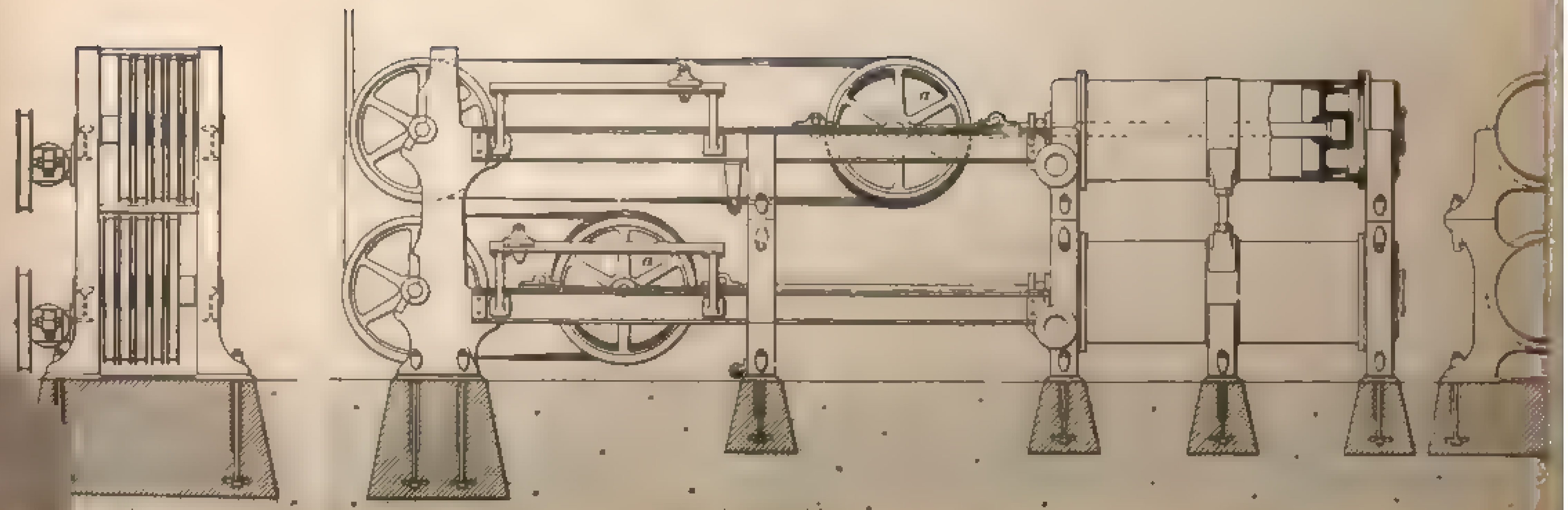


Fig. 14

located at the front end of the cylinder. It will be noticed that the traveling sheaves *a*, *a* are mounted in the crosshead at an angle to the horizontal plane. This is necessary in order that the ropes shall not "ride" off the grooves when the two sets of sheaves come close together at the end of the stroke. This precaution is deemed unnecessary in the compression type, the sheaves being always apart a distance greater than the length of the cylinders.

There are several advantages in the tension type of machines: (1) The piston rods can be considerably smaller. (2) The distance between the fixed and traveling sheaves is smaller, being only about one-half as long as that in the compression type; this is an item of importance when the fact is taken into consideration that teetering of the car is often due to the whipping of the ropes in horizontal machines, which action increases as the distance between the sheaves becomes greater. This action, by the way, is absent in vertical elevators. The whipping of the ropes is reduced as much as possible by supporting rollers shown in Figs. 13 and 14. In the tension type these rollers are supported on a shaft that again rests on guide shoes traveling on rails.

31. The compression type of horizontal elevators has the advantage that no stuffingbox is needed for the piston rod, the water entering behind the piston only. The front end of the cylinder generally has a simple yoke through which the rod passes.

When there is more than one elevator in a building, the cylinders are preferably mounted in pairs on top of each other; such a pair is then called a **double-deck machine,** and this arrangement is shown in Fig. 14.

32. Fast-Service Compression-Type Elevator.—Fig. 15 is an illustration of an elevator machine of the compression type built by the Otis Elevator Company, of Chicago (formerly the Crane Elevator Company). This machine is intended for fast passenger service and is therefore

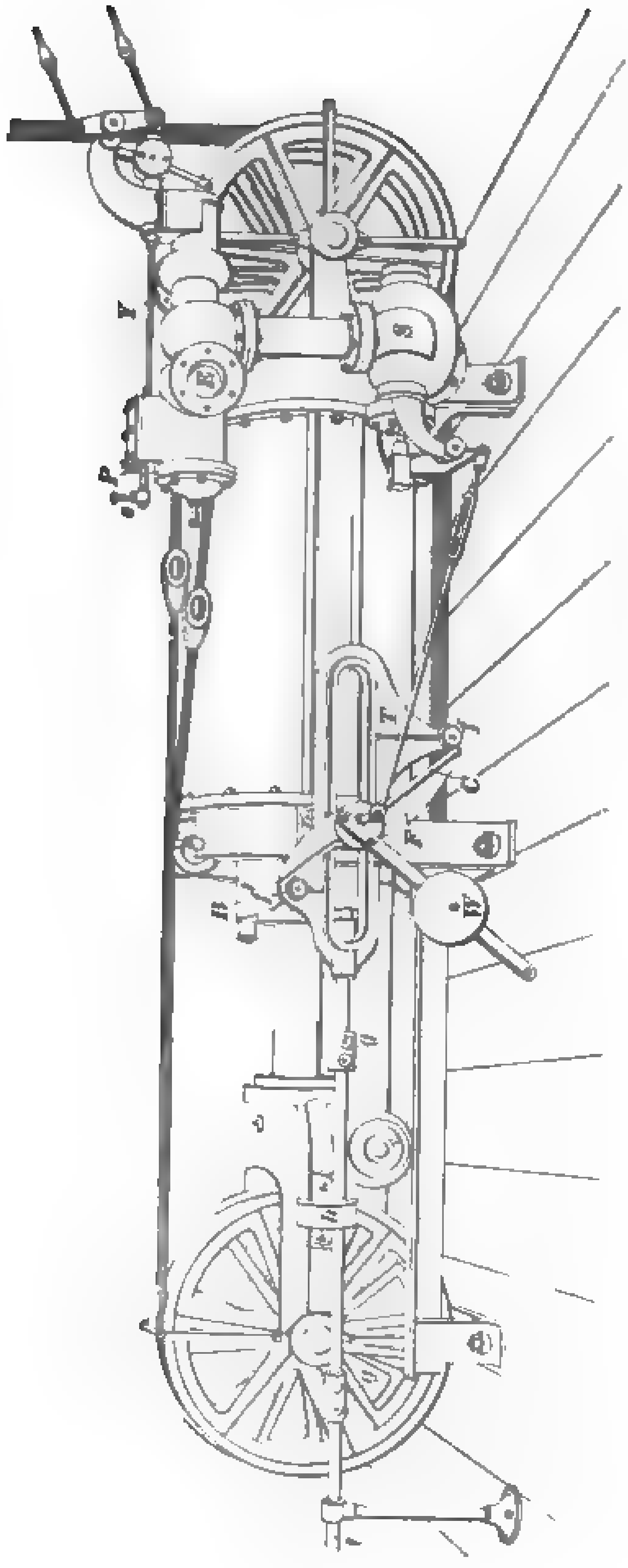


Fig. 15.

fitted with a pilot valve *P*, involving the same principles as the Otis valve described in Arts. **19** and **20**, and has an automatic stop-valve *S*.

33. The pilot valve, main valve, and stop-valve are shown in detail in Fig. 16. The pilot, or auxiliary, valve is a slide

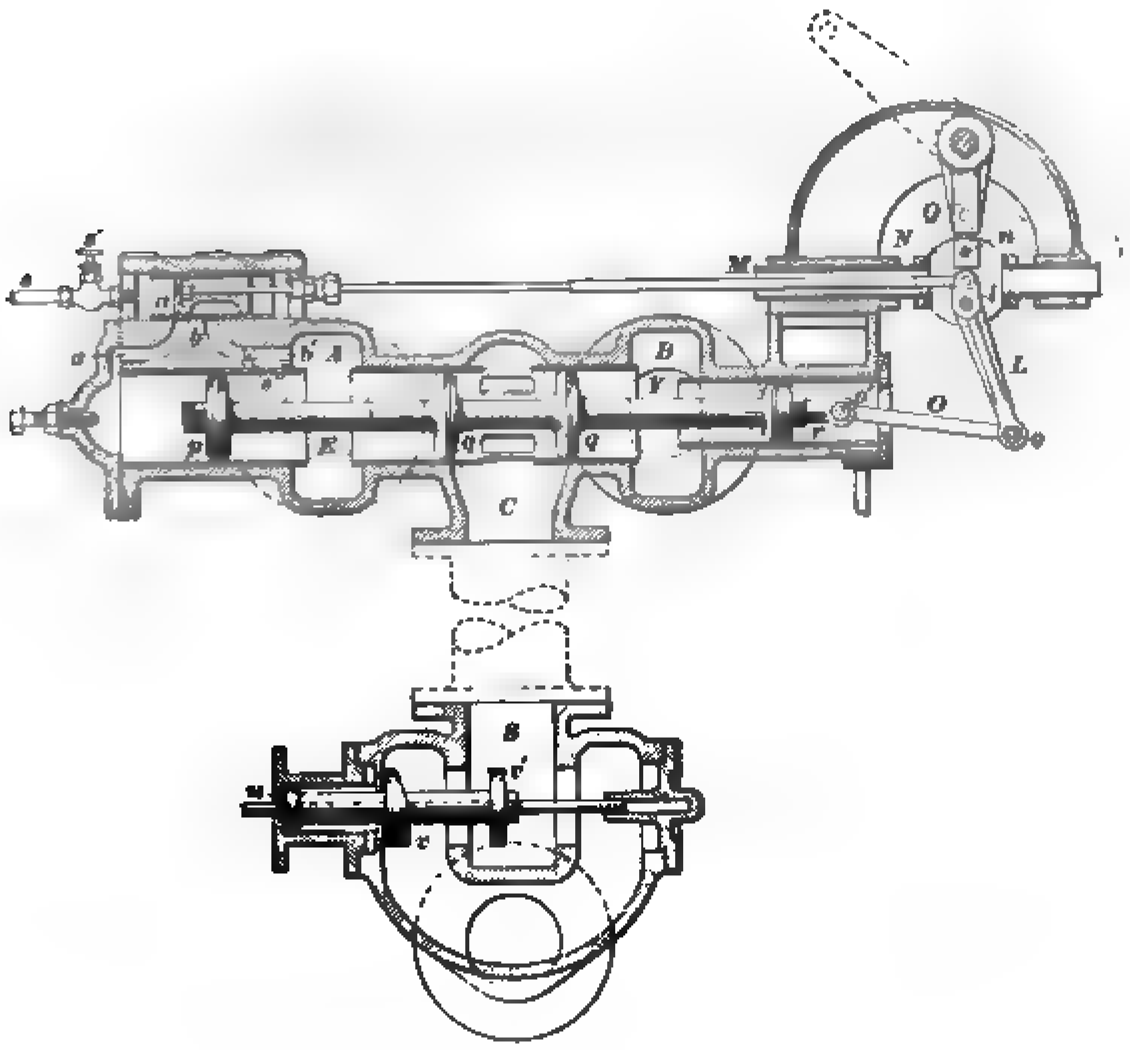


FIG. 16.

valve; its seat has two ports *a* and *b* opening into passages *a'* and *b'* of the main-valve casing. The passage *a'* leads into a space of the main valve behind a piston *p*, while the passage *b'* communicates with a chamber *A* in front of that piston, which chamber, in turn, is connected with the exhaust pipe *E*, Figs. 15 and 16. Of the two other chambers *B* and *C* of the main-valve casing, *B* is connected to the supply pipe *Y*, and *C* to the cylinder by way of the

valve S. The main valve consists of two single pistons and one double piston: the piston p, already mentioned, the double piston q, and the piston r, the latter being of smaller diameter than the others. The valve chest of the pilot slide valve is connected with the supply by a pipe s.

The operation of the valves is as follows: In the position shown the valves are at rest, the port a being closed and the pressure on the piston q towards the left (due to the difference in area of q and r), thus acting against a body of water confined in the space behind the piston p. If the pilot valve is moved towards the right, it uncovers the port a and water under pressure enters the space behind the piston p; the area of this piston being greater than the difference of the areas of q and r, it moves towards the right, thus connecting the chambers A and C; that is, connecting the cylinder with the exhaust, and hence the elevator car moves down. If the pilot valve is moved from its neutral position and to the left, the passages a and b' are connected; that is, the space behind the piston p is put into communication with the exhaust. The excess pressure due to the difference of areas of q and r then causes the pistons to move to the left, opening communication between the chambers B and C; that is, it connects the cylinder with the supply, and hence the elevator car moves up. The speed with which the main valve responds to the pilot valve is regulated by the valve s' in the supply pipe s on one hand and furthermore by a screw s'' that can be made to enter more or less into the passage b' by turning it from the outside.

For the same reason that was given in connection with the Otis pilot valve, Art. **19**, the pilot valve must return automatically to its neutral position. The mechanism that accomplishes this is similar to that used in the Otis valve. The valve stem of the pilot valve is connected to the short arm of a two-armed lever L, which is pivoted at l to the central double disk-shaped piece N of a sliding sleeve M. The long arm of the lever L is connected by means of a link O to the stem of the main valve. The central piece N is connected at n with a one-arm lever Q, the shaft of which

is operated by a lever or sheave actuated by a shipper rope from the car. When the lever Q is thrown to the left, the sleeve M moves to the left, carrying the lever L and the pilot-valve stem with it, the point o' at which the link O connects with the main-valve stem being the pivotal point of the motion. As soon as the main valve commences to move to the left, that is, after the pilot valve is set by the shipper rope, the point l becomes the pivotal point, and the pilot valve is pulled back to its original position. Similar action takes place when the lever Q is moved towards the right.

34. The action of the automatic stop-valve S is as follows: The valve has three pistons v, v', and u, of which the first two serve to close the circular openings leading from the inlet to the outlet. The piston u is at all times actuated by whatever pressure there is on the cylinder, forcing it to the left and thus keeping the circular openings referred to open. The valve stem is connected by a lever and rod to a cam F, Fig. 15, pivoted to the frame of the machine. This cam is ordinarily held, as shown in the illustration, between two rollers f and f' by means of a weight W attached to it. The rollers f and f' are placed on a movable frame T guided horizontally as shown and called the **tappet.** On the guide rod t of this tappet are fastened the limit-stop buttons g, g to the right and left, respectively, of a projection, or arm, h on the crosshead of the traveling sheaves. In either of the extreme positions of the crosshead, the arm h comes in contact with one of the buttons, pushing the tappet T and thus operating the stop-valve and shutting off the communication between the main valve and cylinder.

The valves v and v', Fig. 16, are not fitted very closely, so that there is a certain small amount of leakage, which enables the valve to start back slowly as soon as the pilot valve and main valve are reversed; as soon as the arm h, Fig. 15, leaves either of the buttons g and g, the weight W causes the valve to open quickly and wide. In case the

leakage around the valves v and v', Fig. 16, proves too slight, a small direct pipe connection (not shown) is made between the middle chamber C of the main valve and the top of the cylinder at the closed end. This allows a small quantity of water, which is regulated by a stop-valve, to enter or leave the cylinder independently of the automatic valve S when the pilot valve is reversed so as to give the valve S the start. This pipe connection also serves the purpose of permitting the escape of air that may have accumulated in the cylinder.

35. The hydraulic elevators described are by no means the only ones that are made or that are in operation. They are typical constructions, however, and a person will, if their principles are clearly understood, readily comprehend other designs as well.

PUMPS, TANKS, PIPES, AND FIXTURES.

GENERAL ARRANGEMENT.

36. In cases where a natural water supply or a street main with sufficient pressure is available, the elevator may be directly connected with it. Such cases are rare, however, and therefore a pumping plant is almost always included in an elevator installation. This pumping plant consists usually of one or more pumps, a pressure tank, and a discharge tank suitably connected by piping provided with the necessary valves and other fixtures.

37. A typical installation of an hydraulic elevator is shown in Fig. 17. The pump P takes the water from the discharge tank D and forces it into the pressure tank T, whence it enters the elevator cylinder C through the supply pipe S. It leaves the elevator cylinder through the discharge pipe t, which carries it back to the discharge tank.

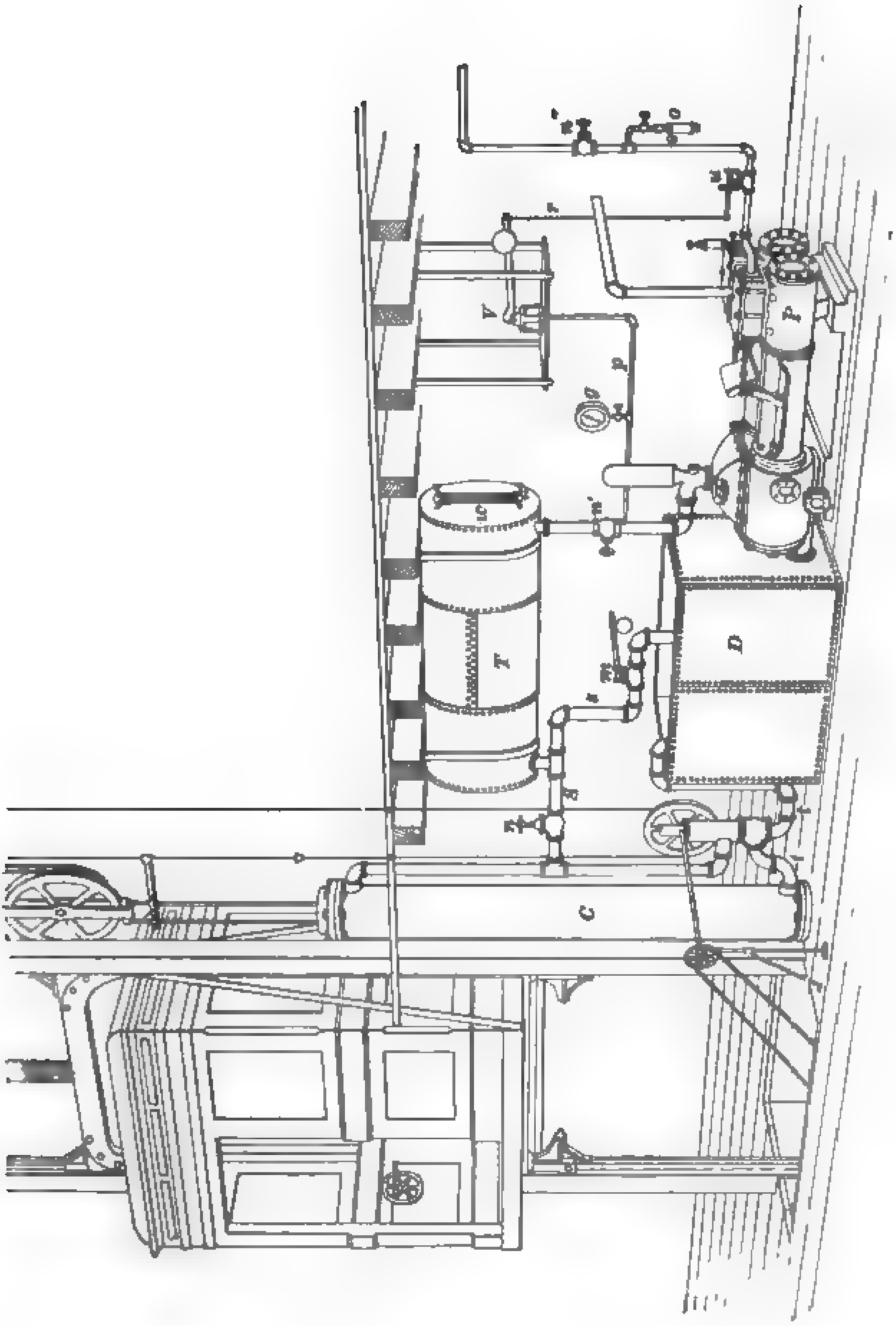


FIG. 17.

The water is thus used over and over again; this is an important item where water rates are high, as is the case in most cities and towns.

PUMPS.

38. Since, with the usual arrangement of pumps, cylinders, and tanks, the pump may work continually while the cylinder takes a quantity of water out of the pressure tank only for every other (the up) trip of the car, the pump need be only large enough to supply the average quantity of water per unit of time, supposing the cars to be running continuously up and down. Since there is more or less interruption of traffic, the pumps will generally even then supply more water than is necessary and will have to be stopped and started frequently For such intermittent service duplex steam pumps or electric pumps are most suitable and are, hence, generally used, although geared pumps, belt-driven pumps, and gas-engine power pumps are occasionally met with.

TANKS.

39. Open tanks, formerly installed in great numbers on the roofs of buildings to furnish the necessary head, are gradually disappearing, and the closed pressure tank, as *T*, in Fig. 17, placed in the engine room, takes its place almost exclusively Such closed pressure tanks are often placed at the top of the building also, thus utilizing both the natural head and the air pressure In such a tank the required water pressure is obtained by having the tank partly filled with air and compressing the same by pumping in the water, so that it is really air pressure that gives to the water the necessary head. By leakage as well as by absorption in the water the quantity of air in the tank gradually grows less and must be renewed. In the smaller installations, such as is shown in Fig. 17, the necessary air supply is obtained through a vent in the suction pipe of the water pump; in large installations separate air pumps are provided for the purpose.

ACCUMULATORS.

40. The pressure used in ordinary closed-tank installations ranges generally between 90 and 120 pounds per square inch. In some cases for high buildings these pressures have to be exceeded, and then hydraulic accumulators are installed instead of the pressure tanks. These high-pressure installations require also different designs of cylinders and other parts of the plant, but since there are but comparatively few of these installations in operation we shall forego treating them in detail.

AUTOMATIC STOPPING AND STARTING DEVICES FOR PUMPS.

41. Kinds of Starting Devices.—The stopping and starting of the pumps are effected automatically by various devices. In one kind of these devices the height of the water in the tank is made use of by means of a float to operate the steam valve of a steam pump or the switch and rheostat of an electric pump; in another kind, the pressure in the tank is utilized to do the same thing by means of a pressure valve. Floats are used only with open gravity tanks.

42. Pressure-Regulated Starting Valve.—A device of the second of the above-named classes is shown in Fig. 17 at *V*. It consists of a pressure valve of much the same construction as a steam-boiler safety valve. It is connected to the pump discharge pipe or directly to the pressure tank by a small pipe *p*, into which is inserted a pressure gauge *g*. The weighted lever of the valve *V* is connected to the throttle valve *u* of the steam pump by a rod *r* in such a manner that the throttle valve shuts off steam when the weight on the lever of the valve *V* is balanced by the required water pressure in the pressure tank, and opens to admit steam when the pressure falls below the required amount. A sight-feed oil cup *o* is generally placed in the steam pipe in advance of the throttle valve *u*, in order

to insure the proper working of the same and to prevent it from sticking.

43. Ford Regulating Valve.—In the device shown in Fig. 18, the two valves [illegible] and [illegible] spoken of in the previous articles are combined into one.

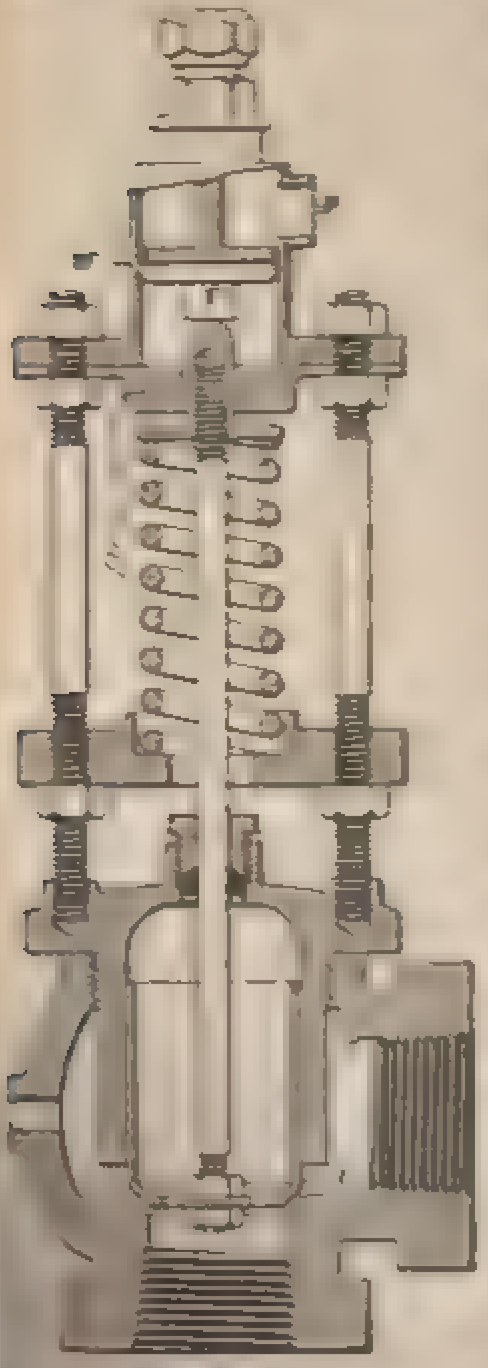


Fig. 18

This device, which is largely used in elevator work and is manufactured by Thomas P. Ford, of New York, consists of a spring-actuated steam valve [illegible] and a water piston [illegible] moving in a little cylinder *H* under the influence of the water pressure. It is easy to see that by adjusting the spring properly the steam valve can be made to close when the water pressure on the piston *F* exceeds a certain required amount. The regulating valve should be placed in the steam supply pipe in a vertical position between the steam chest and an ordinary throttle valve. The oil cup should be placed so as to allow the oil to pass through the regulating valve. The pipe connecting the pressure tank with the pressure cylinder of the regulating valve should be provided with a globe valve and a union next to the valve, in order that the cap may easily be removed for repacking the piston *F*. A drip pipe should be connected with the bottom of the cylinder *H*.

44. Ford Rheostat Regulator.—A device much used in connection with electric pumps and manufactured by

Thomas P. Ford is illustrated in Fig. 19. The purpose of this apparatus is to obtain a comparatively large movement, which is necessary for operating the switch and rheostat of the electric motor.

As in the apparatus shown in Fig. 18, the pressure pipe is connected to a small cylinder *W* in which works a piston *V*

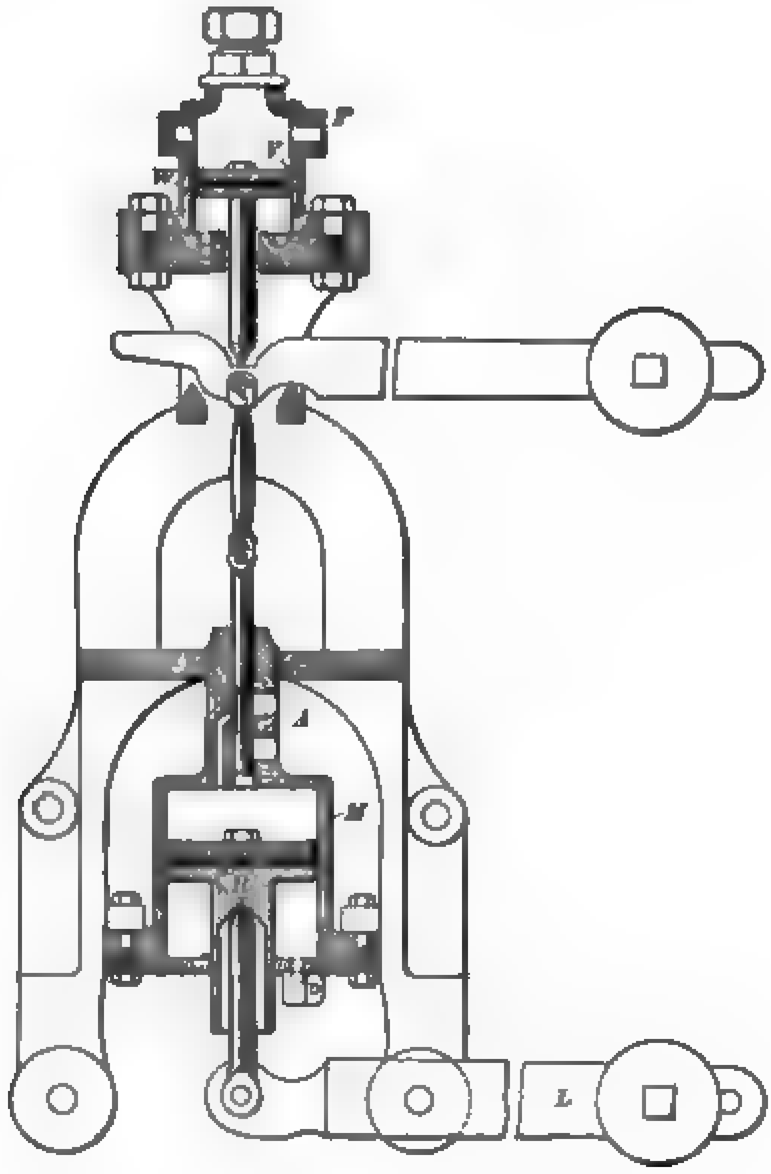


FIG. 19.

against a weighted lever. This lever is, however, not connected directly to the stopping and starting arrangement, but to the piston of an auxiliary hydraulic valve *A*. This valve has an inlet connected to some constant water supply of moderate pressure (not less than 35 pounds per square inch) and a discharge outlet. When the pressure in the

tank falls below the required amount, the piston V rises and carries with it the piston of the auxiliary valve; water is then admitted into the cylinder M of the main valve, causing the piston R therein to be forced down and the outward end of a long double-armed lever L attached thereto to be forced up. This lever is also weighted and to it is attached the lever of a motor starting box. As soon as the pressure in the tank increases, the piston V moves down; by this movement the cylinder M is put in communication with the discharge, whereupon the main valve piston moves up and the end of the lever L down by virtue of the weight attached to it. It is recommended in connecting up this valve to have the water from the constant supply go through a mud-drum placed near the regulator before entering the same.

45. Mason Elevator Pump-Pressure Regulator.—Fig. 20 shows a regulating device much used in elevator work. Referring to the illustration, the operation is as follows: Steam from the boiler enters the regulator at the point marked "inlet" and passes through into the pump, which continues in motion until the required water pressure is obtained in the system, which acts through a ¼ inch pipe connected at a and upon the diaphragm D. This diaphragm is raised by the excess water pressure and carries with it the weighted lever L, opening the auxiliary valve A and admitting the water pressure from the connection b to the top of the piston P, at the same time opening the exhaust port under the piston P, thus allowing the water under this piston to escape through the passage a' shown in dotted lines into the drip pipe d, thereby pushing down the piston, which closes the steam valve and stops the pump.

As soon as the pressure in the system is slightly reduced, the lever L, on account of the reduced pressure under the diaphragm, is forced down by the weights W, carrying with it the auxiliary valve A and thus opening the exhaust from the top of the piston, and at the same time admitting the water pressure under this piston, which is now forced up

and opens the steam valve, again starting the pump. This action is repeated as often as the pressure rises above and falls below the required amount.

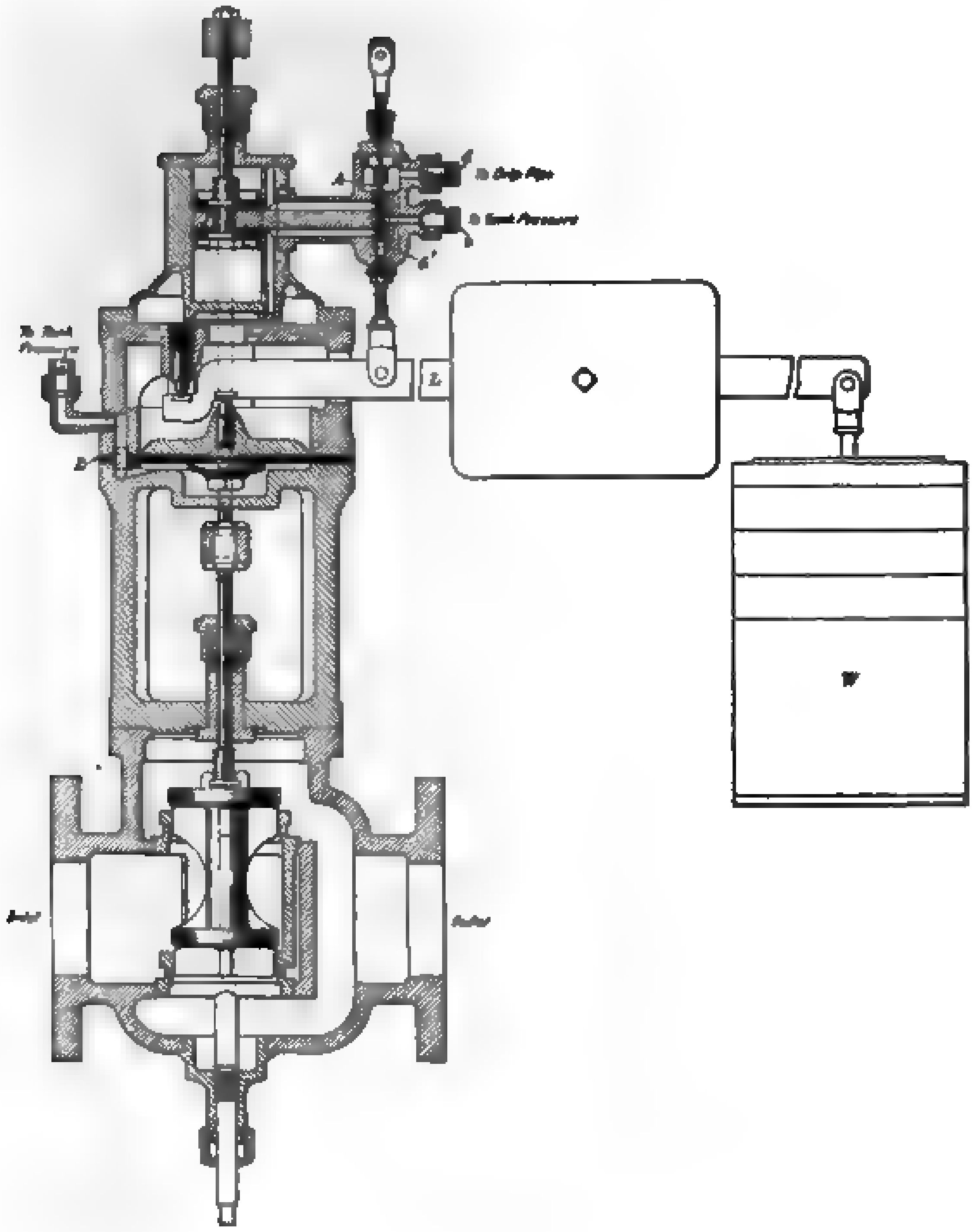


FIG. 20.

46. The Mason regulator is easily adapted for use in connection with a switch and rheostat for regulating electrically driven pumps. Fig. 21 shows such an arrangement

[illegible] as made by the [illegible] Manufacturing Company, a [illegible] motor, and a [illegible] regulator.

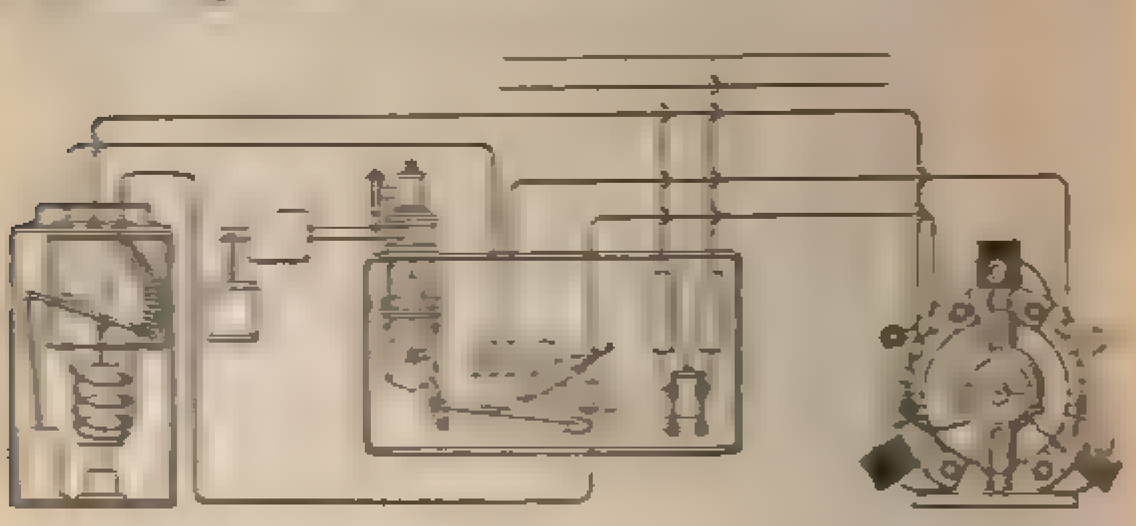


Fig. 21

BY-PASS VALVE.

47. When the elevator service is quite continuous and regular it proves advantageous in many cases, especially with pumps driven electrically or by gas engines, to have the pump run continually and thus to do away with the more or less complicated automatic valve switch and rheostat arrangements. In such cases a **by-pass valve is installed near** the pump, which opens communication between the delivery and suction pipes of the pumps whenever the pressure in the tank becomes excessive. By elevator men, such an arrangement is called a **closed system.**

Fig. 22

Fig. 22 is an illustration of the Ford by-pass valve. Its construction is similar to that of the regulator described in Art. **44,** and it is connected

up in the same manner, a mud-drum being preferably placed near the valve to free the water from any impurities before it enters the auxiliary valve.

SAFETY VALVE.

48. To provide for the emergency, should the regulating devices described in the previous articles stick, and should an excessive pressure accumulate in the tank, a pipe *s* fitted with a **safety valve** *m* (see Fig. 17) and leading from the pressure tank to the discharge tank is generally provided.

WATER GAUGE AND VALVES.

49. Besides the fixtures already mentioned, there is provided a water gauge *w* on the pressure tank and various globe valves *n*, *n'*, and *n''*, Fig. 17, which are used in starting and stopping the plant.

OPERATION AND MAINTENANCE OF HYDRAULIC ELEVATOR PLANTS.

50. Water.—The water to be used in hydraulic elevators should be clear and free from sediment. It should enter the system through a strainer, so as to exclude all foreign matter likely to damage the valves and pistons. The water should be changed at least every three months and the whole system should then be cleaned by washing and flushing. This requires closing down the plant completely.

51. Starting Up and Running.—With all parts supposedly in good working order, joints tight, stuffingboxes, pistons, and valves properly packed, guides, sheaves, and other moving parts well oiled, start the pumps and partially fill the pressure tank; in doing so, the air in the tank will be compressed, but there will not be sufficient air in the tank to give the required pressure. Therefore, when the tank is

about half full of water, open the air vent in the suction pipe of the pump, thus introducing air with the water until the proper pressure is reached, when the gauge shows about one-third of air and two-thirds of water, this being the proportion upon which tanks are generally based to amply supply the necessary amount of water for the cylinders. When an extra air pump is provided, fill the tank two-thirds full of water and supply the air pressure afterwards. The water level indicated above should be carefully maintained by the engineer in charge during the operation of the plant by opening the vent in the suction pipe of the pump occasionally or starting the air pumps, respectively, whenever the water level rises higher through loss of air by leakage or absorption. It is better to have a little more air in the tank than too little, since too small an air volume is apt to cause considerable fluctuation of the pressure during each stroke of the elevator piston.

After the necessary pressure has been reached, slowly open the stop-valve between the tank and the controlling valve, which stop-valve is generally and preferably a gate valve. Next, slowly open the controlling valve, *all air valves or cocks having been previously opened*, to allow the air contained in the cylinder to escape; the air cocks are shown at *a*, Fig. 6, and at *b*, Fig. 8. For the first filling of the cylinder, the controlling valve must be set for *going up*. After all the air is expelled, which can be ascertained by water running from the air cock into the funnel of the drip pipe *m*, Figs. 6 and 8, close the air cock. The elevator is now ready for running.

52. Absorption and Discharge of Air. As already mentioned, the air will be absorbed by the water to a certain extent. This air frees itself in the cylinder and may form a cushion. It is, therefore, occasionally necessary to remove the air. In vertical-cylinder (circulating) systems such an air cushion can form above and below the piston. Air below the piston is automatically removed in the Otis vertical elevator by a piston air valve *c*, Fig. 6, provided for

the purpose, which lets the air into the space above the piston, whence it can be removed through the air cock *a*. When there is air in the cylinder, this will cause the car to spring up and down in stopping. When the quantity of air is small, it can generally be let out by opening the air cock and running a few trips. This should, therefore, be done occasionally. If there is much air in the cylinder the car must be run to the top and the controlling valve set for *going down*. While the car and valve are in this position, open the air cock and allow the air to escape. This may have to be repeated several times before the air is all removed. If the absorption of the air by the water is found to be considerable, it may effectually be prevented by the introduction into the tank of a layer of heavy oil about 4 inches thick. This expedient will, however, have to be resorted to but seldom.

53. Settling of Car.—After all the air is removed close the air cock, as otherwise the car will settle, that is, slowly creep down at the landings. If the air cock is properly closed and the car still shows a tendency to settle, the cause is probably that the piston or valve is leaking and needs repacking. Another cause for settling may be that the piston air valve *c*, Fig. 6, does not properly seat.

54. Groaning Noise in the Cylinder.—If a groaning noise is heard, it may be taken as a sign either that the two piston rods (in the vertical type) are not drawing alike or that the piston packing is worn out and needs renewal. If it is believed that the fault lies with the rods, this may be ascertained by trying to turn the rods with the hands; if one of them will turn, it needs tightening up. If the packing is at fault, the car will settle.

55. Stretching of Cables.—The cables should not be allowed to stretch enough to prevent the car from reaching the top landing, because of the danger of the piston striking the bottom cylinder head.

56. Hand Cable, Limit-Stop Buttons, Back-Stop Buttons.—The hand cable, or shipper rope, as we have called it, should be properly adjusted, neither too tight nor too loose. The limit-stop buttons should be so adjusted that the car will stop at a few inches beyond either extreme landing and before the piston strikes the head of the cylinder. The back-stop buttons should be so adjusted that the valve cannot be opened either way more than to give the car the required speed. In the case of auxiliary, or pilot, valves, the stops on the shipper sheave serve instead of the back-stop buttons.

57. Lubrication.—The plungers in plunger elevators should be kept well greased and clean. A good way to clean and grease the plunger, suggested by the Plunger Elevator Company in connection with their "elevator grease," is to stand at the bottom floor and to run the elevator slowly up while *wiping the plunger dry*. On running the car down again, cover the plunger with a thin coat of grease, rubbing it on and spreading it even with the hands. The plunger should be dry when the grease is applied; otherwise the grease will not stick. The inside of the cylinder should be lubricated about every two weeks with cylinder oil. Oil cups are generally provided for this purpose. The Otis Elevator Company, of Chicago (Crane Elevator Company), say the following in regard to lubrication: "The most effectual method of lubricating the internal parts of hydraulic-elevator plants, where pumps and tanks are used, is to carry the exhaust-steam drips from the foot of the pump-exhaust pipe to the discharge tank, thus saving the distilled water and cylinder oil. This system is invaluable when water holding minerals in solution is used, as these minerals greatly increase corrosion."

Horizontal machines operated by city pressure are best lubricated with a heavy grease, applied either mechanically or by means of a piece of waste on the end of a pole. The former method serves as a constant lubricator, while in the latter case greasing is often neglected and, in consequence, packing lasts but a short time.

Mr. Ford recommends as a lubricant for his valves, described in Arts. **43, 44,** and **47,** common soap applied once a month.

58. Bushing Sheaves.—If the traveling-sheave bushing is worn so that the sheave binds or if the bushing is nearly worn through, turn it half around and thus obtain a new bearing. If it has been turned before, put in a new bushing.

59. Precautions Against Freezing.—Precaution must be taken against the water freezing in any part of the system. If the cylinder and connections must be located in an exposed place, they should be protected against frost by building an air-tight box, open at the bottom, around them; a small gas jet should be kept burning at the bottom, or when steam is available a coil should be placed near the cylinder. Plunger-elevator cylinders are exempt from the danger of freezing. Supply pipes outside of the building are best protected by burying them in the ground below the freezing line, say 6 feet. If this cannot be done, they should be covered with non-conducting material, the same as is used for steam pipes. If in cold weather the elevator service is to be stopped for any length of time the water must be drained off, care being taken that this is done thoroughly. This applies especially to small pipe connections for drips, vents, etc., which should be free from bends, loops, or sags in which water may be left to freeze after the system has been drained.

60. Closing Down Hydraulic Elevators.—We will imagine that for some purpose, as prevention of freezing, change of water, etc., the plant is to be closed down. After removing the lower limit-stop button, run the car slowly to the bottom. Next shut off the supply by closing the valve provided for the purpose in the supply pipe, as the valve *n* in Fig. 17. In the plunger type of elevator machine, the valve and connections only are thus drained, the cylinder remaining full of water around the plunger, which, however,

does no harm, since being far underground the water will not freeze. In the horizontal machines, running the car down and closing the supply leaves both cylinder and valve free of water. In the vertical (circulating) machine, however, the cylinder and circulating pipe are still full of water when the car is down and must be drained. For this purpose, open the air cock and the drain-pipe valve *d*, Figs. 6 and 8. Throw the valve for *going up* to empty the cylinder through the discharge pipe. Next throw the valve for *going down* to empty the circulating pipe through the drain pipe. After all water is drained off, grease the cylinder with heavy grease if the machine is of the horizontal type, and grease the piston rods if of the vertical type.

61. Packing Plunger and Piston Rods and Stuffingboxes.—Stuffingboxes that must be repacked from time to time occur in the plunger type, the vertical type, and the horizontal tension type of hydraulic elevators. For repacking the stuffingboxes, it is neither necessary nor expedient to drain the system.

For packing plunger stuffingboxes, run up the car sufficiently to be enabled to work conveniently in the pit, shut the three-way controlling valve and the supply stop-valve between the tank and the controlling valve. Block up the car, then remove the gland of the stuffingbox and renew the packing; replace the gland, screwing up the bolts just tight enough to prevent leaking, open the supply stop-valve and then slowly the controlling valve, setting it for *going up*. Remove the blocking.

62. Various materials are used for packing plunger stuffingboxes. For the smaller sizes, such as sidewalk-elevator plungers, fibrous packing, such as hemp, flax, or cotton, is used exclusively. For large plungers cup leathers are probably the best packing. But since the cup-leather ring must be split open in order to introduce it into the box, much of its value is impaired; therefore, fibrous packing is much used.

63. To retain the cup-leather principle and at the same time to avoid the objection to the butt joint, multiple cup leathers may be used. Fig. 23 shows a plan that is said to have proved very satisfactory. The packing consists of split leather rings, or even of ring sections, of V-shaped cross-section. The edges of these rings are cut down sharp, in consequence of which they act in much the same manner as cup leathers. The single sections are, of course, introduced so as to break joints. This kind of packing is very tight, but is likely to create a great deal of friction.

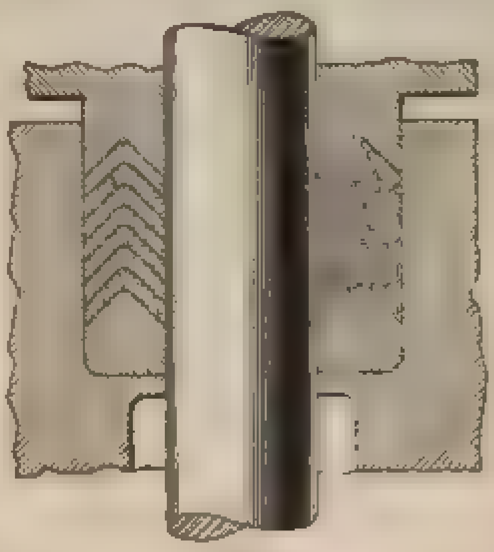


FIG. 23

64. A much better arrangement is shown in Fig. 24. This packing, known as **Wright's elevator packing,** con-

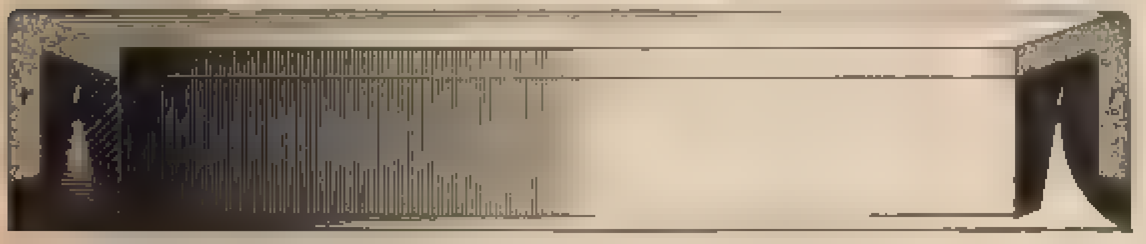


FIG. 24

sists of a split rubber ring *l* of cup-shaped cross-section and a split leather ring *r* of L-shaped section. Both rings are placed in the stuffingbox so as to break joints.

65. For packing piston-rod stuffingboxes, close the supply stop-valve and open the air cock to make sure that there is no pressure in the cylinder; remove the followers and glands of the stuffingboxes and renew the packing. Screw down the followers only tight enough to prevent leaking. Fibrous packing is used exclusively.

66. Packing Vertical Cylinder Pistons.—In some designs of vertical elevators the piston can only be packed from the top, as in the elevators shown in Figs. 5 and 8. In others, provision is made for packing the piston either from the top or bottom, as in the Otis elevator shown in Fig. 6. In others, again, the piston can be packed only from the bottom, as in the elevator shown in Fig. 11.

67. To pack a vertical cylinder piston from the top, run the car to the bottom and close the stop-valve in the supply pipe. Open the air cock at the head of the cylinder and also keep open the valve in the drain pipe from the side of the cylinder long enough to drain the water in the cylinder down to the level of the top of the piston. Now remove the top head of the cylinder, slipping it up the piston rod out of the way and fastening it there. If the piston is not near enough to the top of the cylinder to be accessible, attach a rope or small tackle to the *main cables* (not the counterbalance cables) a few feet above the car and draw them down sufficiently to bring the piston within reach. Remove the bolts in the piston follower by means of a socket wrench. Mark the exact position of the piston follower before removing it, so that there will be no difficulty in replacing it.

In the elevators shown in Figs. 5 and 8 fibrous hemp packing is used. In the design shown in Fig. 6, a combination of cup-leather and duck packing is used. On removing the follower of this piston, a leather cup *l* is found turned upwards, with coils *u* of $\frac{5}{8}$-inch square duck packing on the outside. This duck packing should be removed and the dirt cleaned out; also clean out the holes in the piston through which the water acts on the cup. If the leather cup is in good condition, replace it and on the outside place three new coils of $\frac{5}{8}$-inch square duck packing, being careful that they break joints and also that the thickness of the three coils up and down does not fill the space by $\frac{1}{4}$ inch, as in such a case the water might swell the packing sufficiently to cramp it in this space, thus destroying its power to expand. If too tight, strip off a few thicknesses of canvas.

Replace the piston follower and let the piston down to its right position. Replace the cylinder head and gradually open the gate valve in the supply pipe, first being sure that the operating valve is on the center. As soon as the air has escaped, close the air cock and the elevator is ready to run.

68. To pack vertical-cylinder pistons from the bottom, remove the top limit-stop button and run the car up until the piston strikes the bottom head of the cylinder. Secure the car in this position by passing a strong rope under the girdle, or crosshead, and over the sheave timbers. When secured, close the gate valve in the supply pipe, open the air cock at the head of the cylinder, and throw the controlling valve for the car to *go up*. Also open the valve in the drain pipe from the side of the cylinder and from the lower head of the cylinder, thus allowing the water to drain out of the cylinder. When the cylinder is empty, throw the valve for the car *to descend*, in order to drain the water from the circulating pipe.

In cases of tank pressure, where the level of water in the lower tank is above the bottom of the cylinder, the gate valve in the discharge pipe will have to be closed as soon as the water in the cylinder is on the level with that in the tank, allowing the rest to pass through the drain pipe to the sewer. When all water is drained off, proceed as directed in the previous article in renewing the packing. To refill the cylinder after packing, close the valves in the drain pipes, leave open the air cock at the head of the cylinder, leave the controlling valve in the position to descend, and open the gate valve in the discharge. Slowly open the gate valve in the supply pipe, allowing the cylinder to fill gradually and the air to escape at the head of the cylinder. When the cylinder is full of water, close the air cock and put the controlling valve on the center. The car can then be untied, the limit-stop button reset, and the elevator is ready to use.

69. Packing Horizontal Hydraulic Elevators.—In a compression-type elevator run the car to within 1 foot of the extreme top and secure it to the overhead beams with a

chain or rope. Close the gate valves in the supply and discharge pipes and open the air cock and valve in the drain pipe, emptying the cylinder. Remove the buffer across the front (open) end of the cylinder and slide it along the piston rod out of the way. Remove the follower of the piston. With a hooked piece of wire remove the old packing. Raise the piston head until it is in the center of the cylinder. If the cylinder is found to be in good condition, cut off four rings of square lubricated fibrous packing 9 inches longer than the circumference of the cylinder. Place the two ends of a ring together and form tucks with the balance. Force in these tucks one at a time with a hardwood stick until all are level against the head. Proceed in the same manner with the remainder of the packing. Arrange the packing so that the joints in the different rings do not come together.

If the cylinder is badly worn, use square pure-rubber packing for the first and last ring, and make these but 1 inch larger than the circumference of the cylinder. This rubber insures a backing for the fibrous packing. After putting the packing in position, replace the follower and screw on the nuts with the fingers until the follower is close to the packing. On two of the studs opposite each other will be found jam nuts. Set these out against the follower and tighten with a wrench. Replace the buffer. Close the drain valve and set the controlling valve for going up. Open the gate valve in the supply pipe and fill the cylinder. When the cylinder is filled, close the air cock. As the car in the first place was not at the extreme top, the pressure in the cylinder will run the piston head against the buffer and the car will ascend to the extreme top. The fastenings may then be removed. Throw the controlling valve on the center and open the discharge. The elevator is then ready to descend. Do not make any trips until the cylinder is thoroughly greased. Continue greasing twice a week.

In the course of time, leaks will occur in the cylinder. Loosen the jam nuts back of the follower and set up the nuts on the studs equally until the leak is stopped. Then retighten the jam nuts.

70. In the tension type of horizontal hydraulic elevator, the procedure is exactly the same, with the exception that there is no buffer to be removed, the open end of the cylinder being at the back.

71. Packing the Controlling Valves.—Run the car to the bottom, close the supply valve, and drain the system as previously described. When the water is all drained off take off the cap. After marking the exact position of the various parts in relation to one another, remove the valve proper and renew the packings, placing the new ones in the same position as the old ones. Before refilling the cylinder close the valves in the drain pipes, but leave the air cock at the head of the cylinder open and be careful that the valve is in the position for the car to go down. Gradually open the gate valve in the supply pipe. When the cylinder is filled, close the air cock and open the gate in the discharge pipe.

72. Packing Material.—Fibrous packing is furnished by the trade in the form of a square braided fiber impregnated with a greasy substance. The material used is hemp, flax, or cotton. It is claimed by some that cotton is a more suitable material, being more elastic, softer, and more absorbent for grease. In using it, it is important that it should be well soaked in boiling tallow for several hours to exclude with certainty all air from the pores.

73. Leather for cups should be of the best quality, of an even thickness, free from blemish, and treated with a waterproof dressing. The cups should be of sufficient stiffness to be self-sustaining when passing over the perforated valve lining. Elevator builders generally make and furnish packings to fit their machinery, and it is recommended to get supplies from them. When ordering cups, the pressure of water carried should be specified, as the stiff cups intended for high pressure would not set out against the valve lining when low pressure is used.

ELEVATORS.

(PART 4.)

CAR SAFETIES.

PURPOSE.

1. The term **car safeties** applies to safety devices that in cases of emergency prevent the car from falling unretarded to the bottom of the shaft. All these devices, with the exception of air cushions, consist primarily of catches in the shape of wedges, pawls, etc. that lock the car to the guides. They differ, however, in the means by which these catches are set in operation. In some designs of car safeties, only the breaking of the hoisting cable or cables or its becoming slack through a temporary sticking of the car in its descent will operate the safety catches. In other designs, excessive speed of the car is relied on to operate them.

SLOW-SPEED CAR SAFETIES.

2. Fig. 1 shows the simplest form of a car safety intended to operate at the breaking of the hoisting cable or its becoming slack through a temporary arrest of the car. The hoisting cable is attached to a bolt *F*, which is free to slide in its hole in *d*, but has an enlarged head on the bottom through which the curved spring *e* passes. The lower end *c*

of the bolt is slotted to receive one end of the bell-crank levers E, E, which are pivoted to the uprights of the car. The other ends of the bell-crank levers carry pawls f, f, which are spring-actuated and adapted to enter between suitable ratchet teeth on the guides. The pawls are normally held out of engagement with the teeth, the spring e being compressed by the load. Should the cable break or become slack for any reason, such as a temporary arrest of the car in its descent, the tension in the spring e would be relieved and the pawls would consequently engage the ratchet teeth, preventing the car from falling.

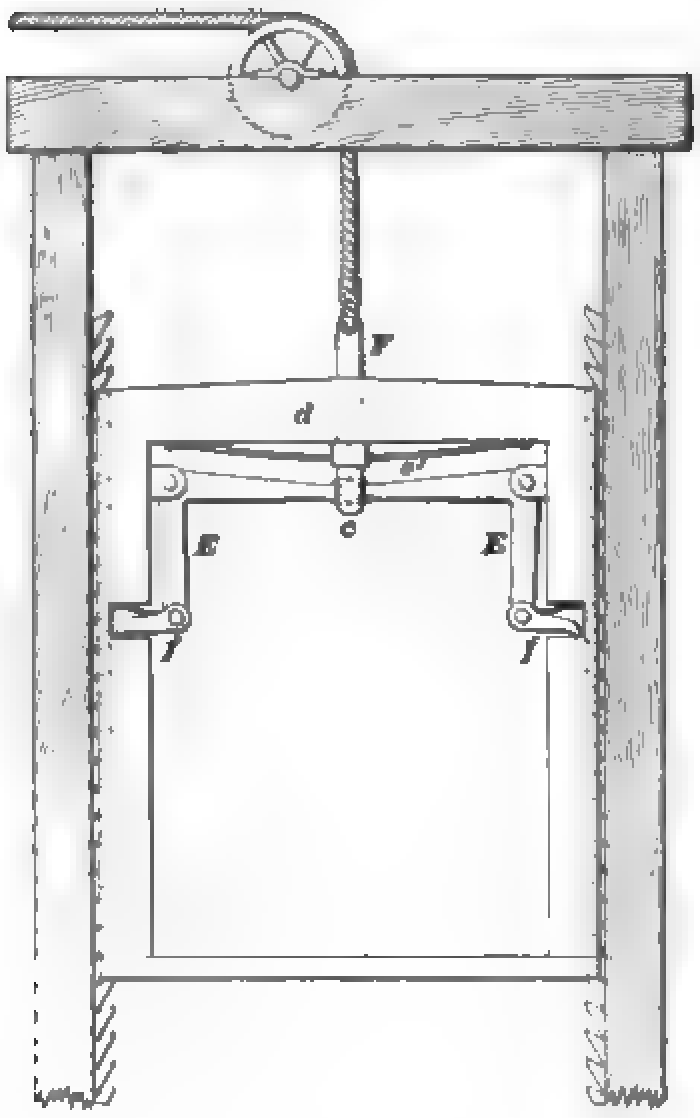


FIG. 1

3. Pawl-and-ratchet arrangements, such as are shown typically in Fig. 1, are now but seldom used; they are suitable only for slow elevators. The pawl is generally replaced by a wedge that enters between the guides and the guide shoes. Fig. 2 is an example of a car safety of this kind. The cable is attached, as in the previous case, to a spring-actuated bolt or stirrup F carrying an S-shaped plate S, to which the links L, L are attached. These, in turn, are connected to levers E, E. When the cable breaks, the helical springs surrounding the legs of the stirrup force down the plate S, lifting up the

outer ends of the levers *E*, *E*. These levers, in turn, then press on serrated wedges *W*, *W* contained in pockets of the guide shoes in such a manner that ordinarily they remain

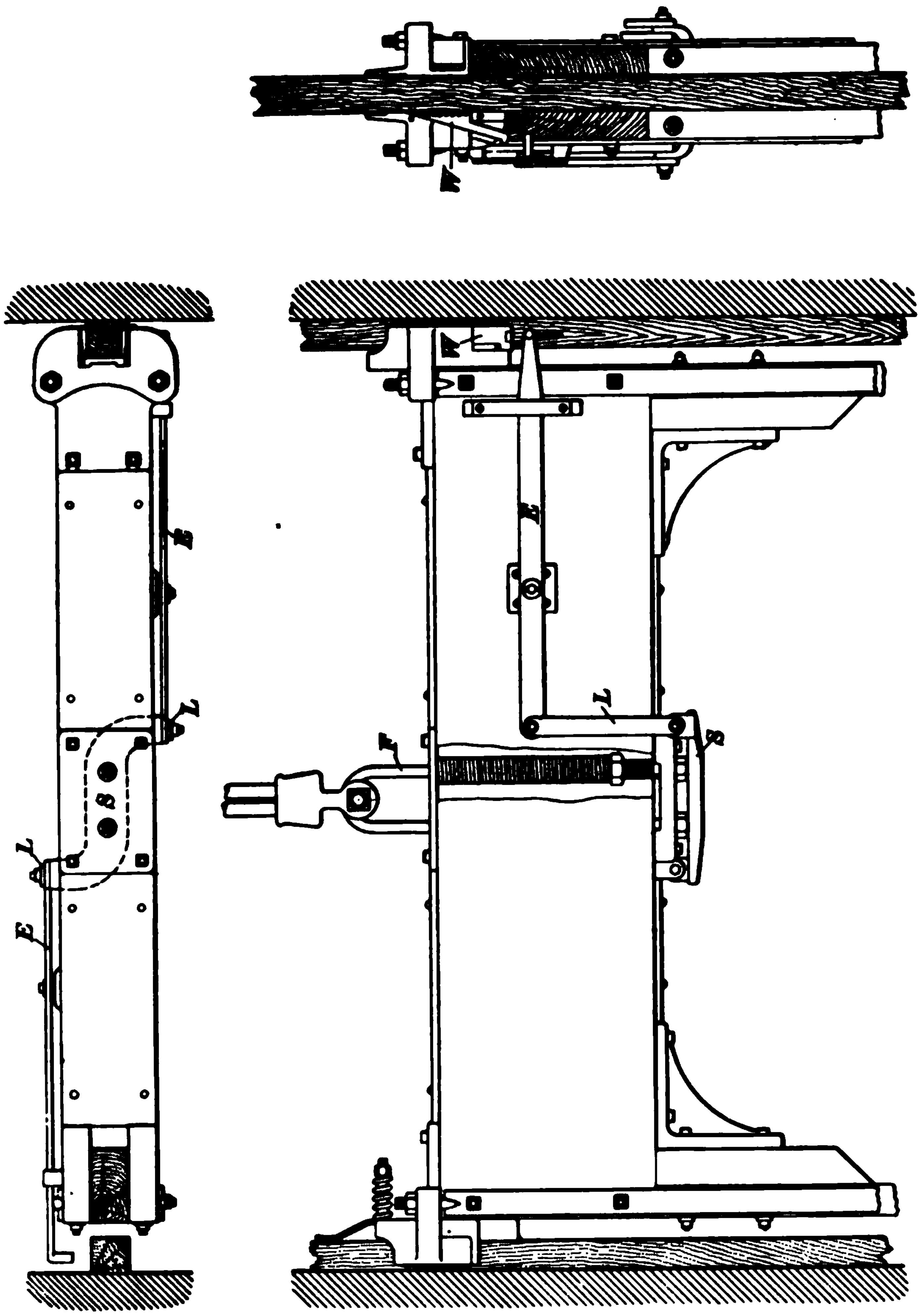


FIG. 2.

by gravity out of contact with the guides. The pressure of the lever ends forces them against the guides and the downward motion of the falling car wedges them tight, the

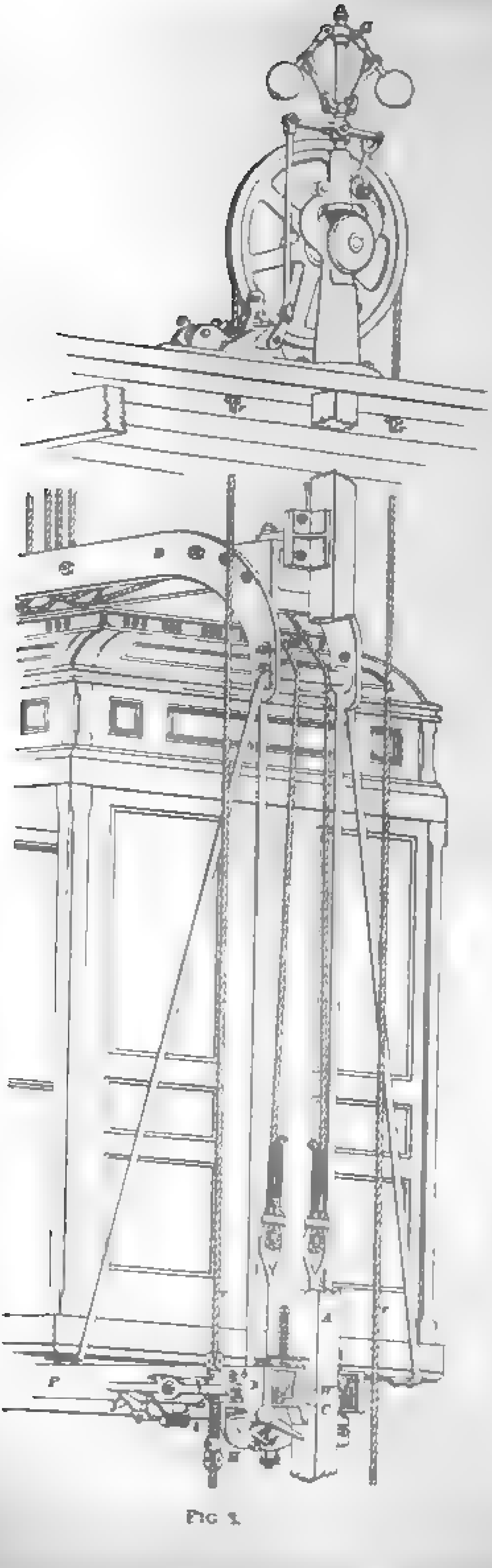


FIG. 2

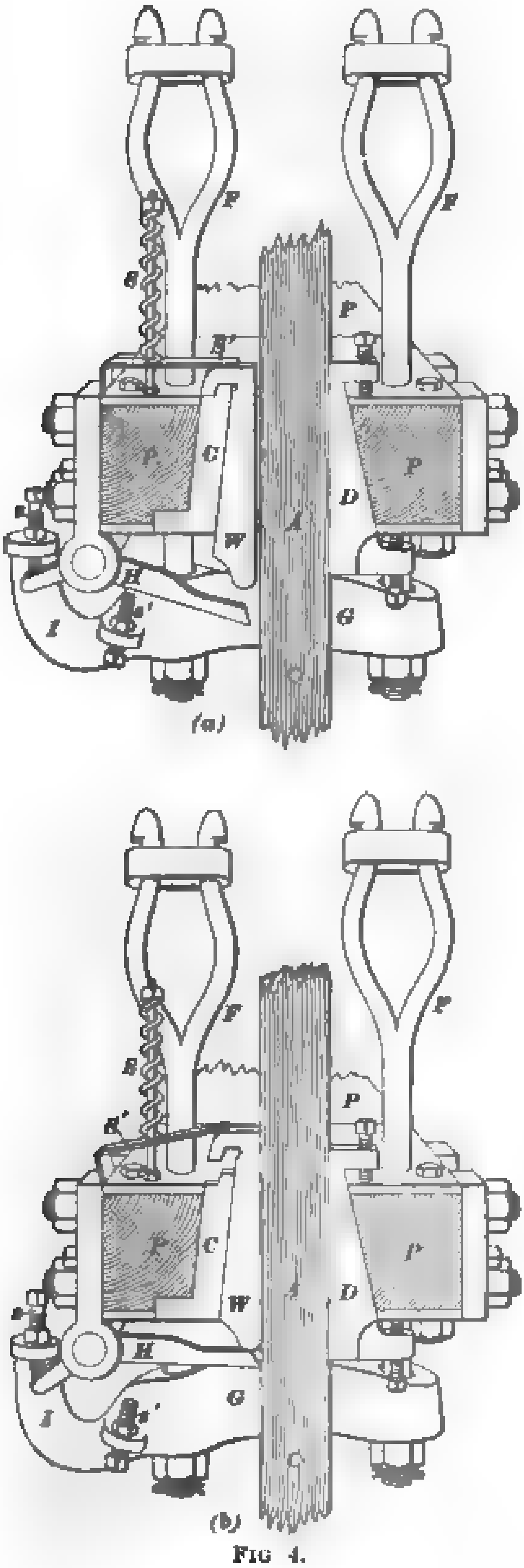


FIG. 4.

serrations or teeth burying themselves into the wood of the guides. When the car is again lifted, the wedges disengage themselves. This safety is regularly used by the A. B. See Manufacturing Company on their freight elevators with wooden guides.

4. It will be noticed in the arrangement shown in Fig. 2 that two cables are used, but in order that the safety mechanism should operate, both cables must break or become slack at the same time.

5. In order to make the safety device respond to the breaking, slacking, or even stretching of one of several cables used, the cables must be independently attached to wedge-operating levers. Figs. 3 and 4 show an arrangement of this kind known as the **Otis gravity-wedge safety.** It consists of a so-called **safety plank** P of hardwood placed under the platform of the car, and into the ends of which are let

the guide shoes, each of which consists of a fixed jaw *C* and an adjustable one *D*, the latter being very clearly shown in Fig. 4 (*a*) and (*b*). Between the fixed jaw and the guide *A* is inserted a wedge *W*, which is normally held by gravity in such a position that the shoe can slide freely over the guide. The cables are attached, in the manner shown in Fig. 3, to the **shackle rods** *F*, Fig. 4, which, in turn, pass through an **equalizing lever** *G* pivoted in a suitable manner to the safety plank *P*. From the shackle rods the cables are carried upwards over rollers in a wrought-iron **girdle** *B*, Fig. 3, at the top of the car. By virtue of the equalizing levers, each of the four cables carries an equal strain, and as long as all cables are equally sound the equalizing levers will remain in their original position, that is, horizontal, as shown in Fig. 4 (*a*). As soon, however, as one of the cables breaks or even stretches more than its neighbor, the equalizing lever will tilt, as shown in Fig. 4 (*b*). An arm *I* of the equalizing lever carries a setscrew *s*, which is so adjusted that when the lever tilts down it will strike the end of a **finger** *H* mounted on a shaft under the safety plank. This finger then presses against the wedge *W*, making it engage the guide. Another setscrew *s'* is provided on the arm of the equalizing lever and has the same effect on the finger *H* in case the lever tilts the other way. It is thus seen that in case any of the cables become slack, stretched, or broken, the car will be stopped. The car may then be lifted by the other cables, but it cannot be lowered until the damaged cable is replaced. The spring *S* acting on the spring plate *S'* keeps the wedge *W* in place and prevents it, under normal conditions, from being drawn into engagement by mere sliding contact with the guide.

HIGH-SPEED CAR SAFETIES.

6. Safeties operated by the breakage, slacking, or stretching of a hoisting cable are today not considered sufficient except for very slow-speed elevators. In all high-speed elevators the catches are set into operation by excessive

speed of the car, and the most generally adopted plan to effect this is the employment of a centrifugal governor placed either on top of the hoistway or carried on the car, and operated by an endless rope attached to the car or some fixed point. Such an arrangement is often found in addition to safeties to be operated by breaking cables, notably when city ordinances demand the latter.

7. An example of such a safety device is given in the Otis elevator shown in Fig. 3. The finger shaft mentioned in Art. **5** can also be operated by a rope *r* attached to a lever *l*, which, in turn, presses on a finger *f* on the finger shaft. The rope *r* passes around the pulley of a centrifugal governor *G*, Fig. 3, on top of the hoistway and an idler at the bottom. The idler is mounted on a crosshead that slides vertically in short guides and is weighted so as to give the rope *r* the proper tension. The centrifugal governor, by the outward motion of the balls, operates a clutch consisting of two eccentrics *g* and *g'*, between which the rope *r* passes and which are geared together so as to grasp and pinch the rope when the balls move out too far, owing to excessive speed. The shaft of the eccentric *g'* has a crank *o* connected by a rod to the operating lever of the ball governor *G*. The eccentric *g'* is, however, loose on its shaft and has fastened to it an arm *a* having a stop pin *i*, against which the crank *o* strikes at excessive speed of the governor, bringing the eccentrics together so as to just bite the rope *r*. The continuing motion of the rope then pulls the eccentrics over fully, finishing the grip. The governor thus only starts the gripping of the eccentrics. It will be easily understood that reversing the motion of the car will throw the eccentrics back into their original position. The gripping of the rope causes the descending car to turn the lever *l* left-handed; this, in turn, rotates the finger shaft through engaging the finger *f*, and the finger *H* then operates the wedge *W*; the guides are thus gripped.

8. Another governor-operated device that is extensively used by the Otis Elevator Company in connection with steel

guides is shown, together with the whole car frame, in Fig. 5, and in detail in Fig. 6. It will be noticed from the drawing that the four hoisting cables are not connected in any way

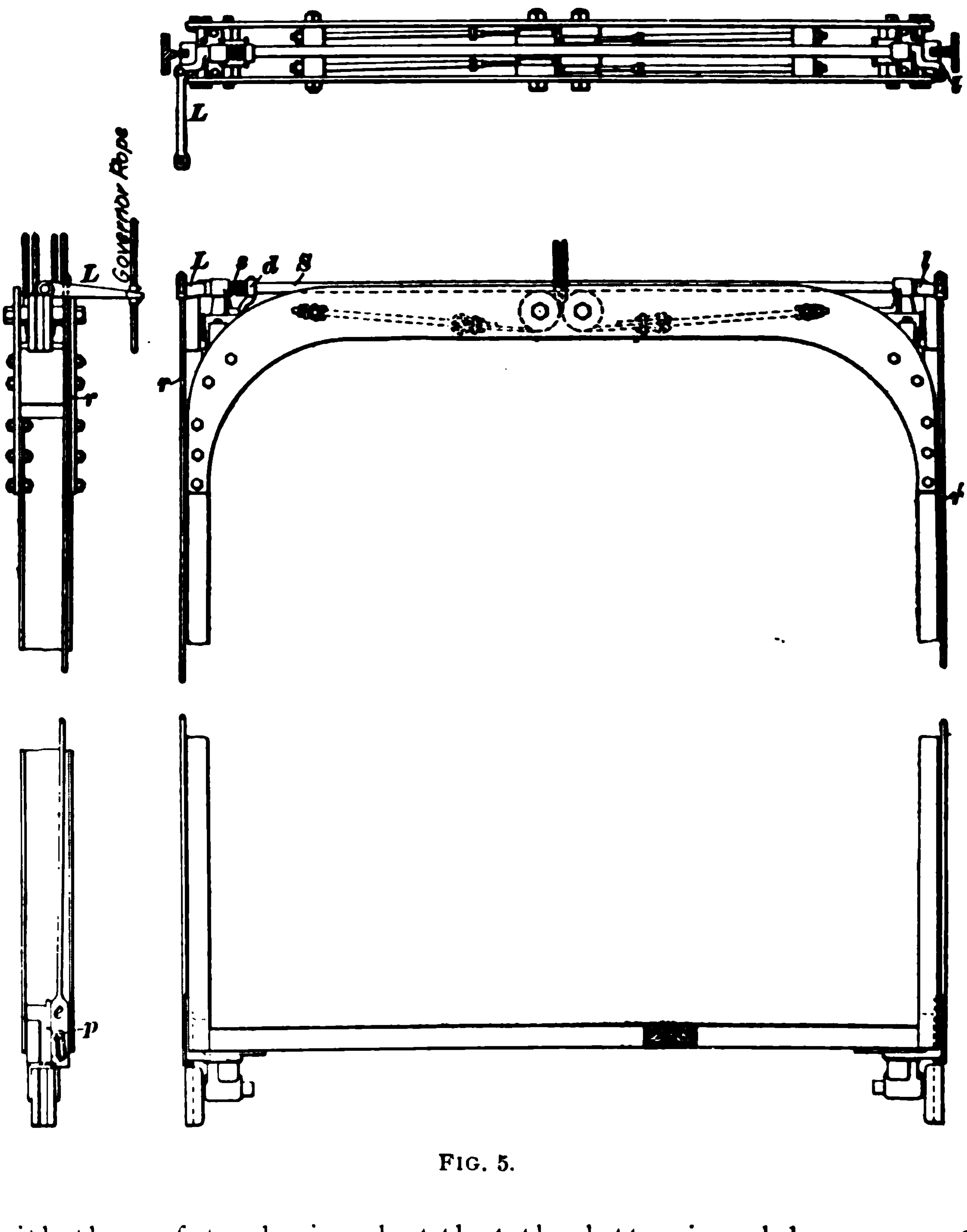


FIG. 5.

with the safety device, but that the latter is solely operated by the governor rope. The rope is attached to a lever *L*, which is fastened to a shaft *S* running across the top of the car frame. This shaft is held, normally, in a fixed position by a helical spring *s* and a stop-collar, or dog, *d*, resting against the guide-shoe casting. A little nearer the fulcrum of the

lever L a rod r is attached to this lever; and to a separate lever l on the other end of the shaft S a similar rod r' is attached. These rods extend downwards to the safety plank, where they have flattened ends e, Figs. 5 and 6. A slot in each of these flattened ends serves to guide the rods by means of a pin p. On the under side of the flattened end is a shelf f, Fig. 6, that supports a loose roller r, serrated on

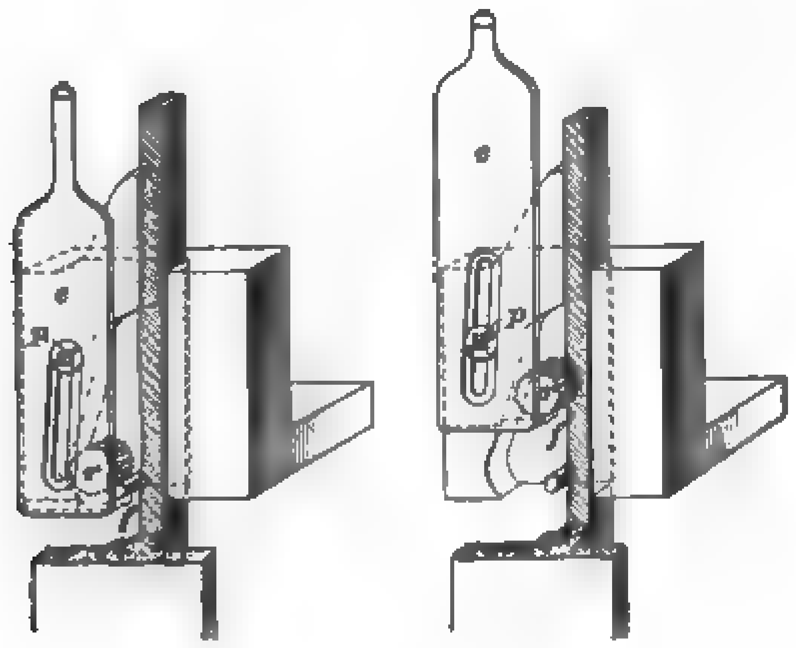


FIG. 6.

its cylindrical surface and contained in a pocket formed in the casting on the end of the safety plank. This pocket is so formed that if the roller r be lifted, it will be wedged in between the back wall of the pocket and the side of the T-shaped guide rail. The operation of this arrangement will be easily understood from the above brief description and Fig. 6, which shows the clamping roller in action and out of action.

9. In some governor-operated safeties the governor is carried under the platform of the car. Fig. 7 shows an arrangement of this kind as built by the A. B. See Manufacturing Company, and is intended for use with steel guides. Fig. 7 (*a*) is a bottom view, while Fig. 7 (*b*) is an

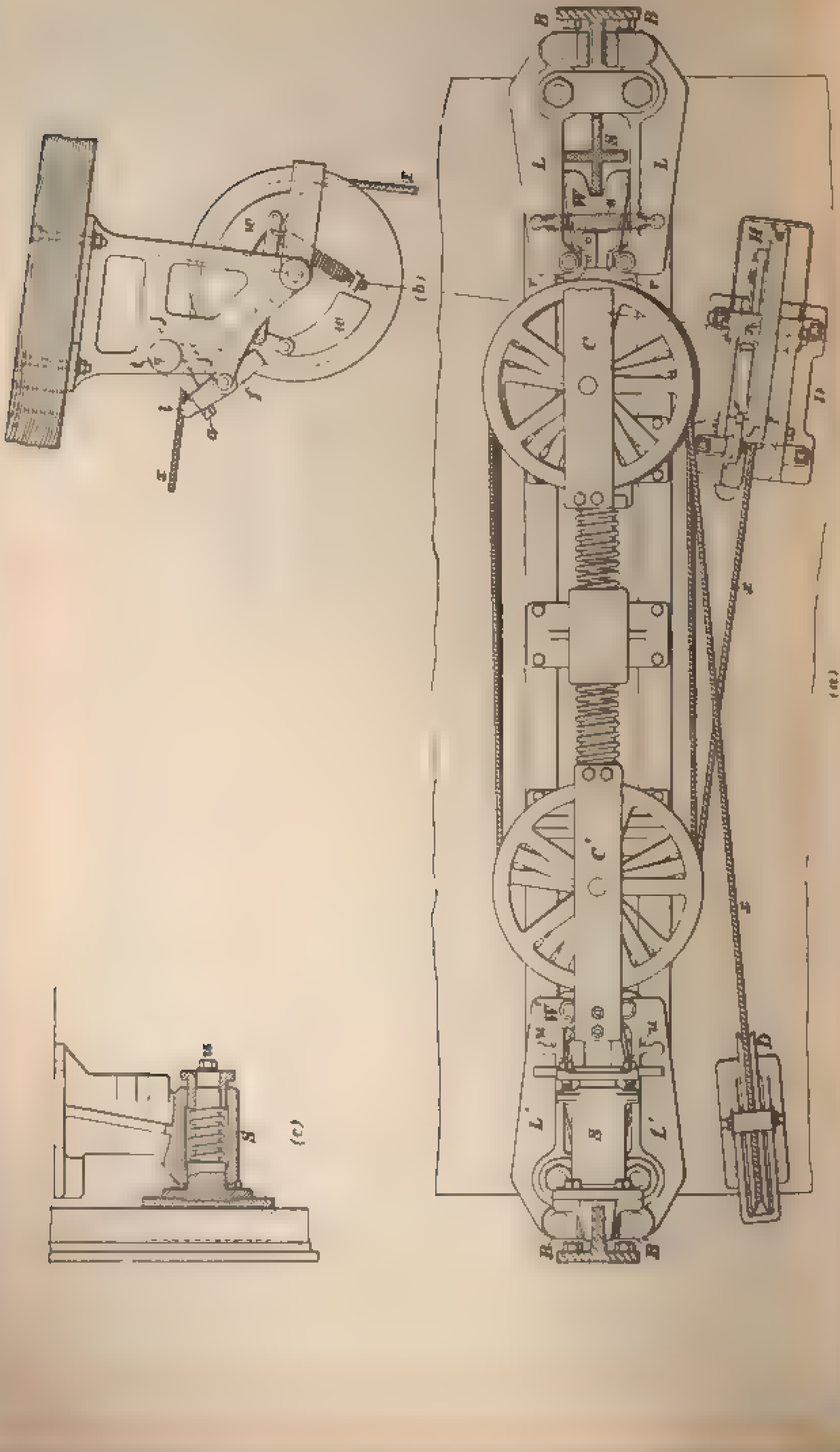


Fig. 7.

elevation of the governor and cable-gripping device. To the guide-shoe castings *S*, shown in side view in Fig. 7 (*c*), shown complete at the left of Fig. 7 (*a*), and at the right with the guide shoe proper and its sleeve removed, are pivoted the levers *L*, *L* and *L'*, *L'*. The short arms of these levers carry grip blocks *B*, *B* and *B'*, *B'*, which are intended to close upon the guide rails in case of excessive speed. The long arms of the levers *L*, *L'* carry rollers *r*, *r*. Each pair of levers is connected by a spring *s* that normally holds the grip blocks off the guide rail. The governor rope *x* passes up from the bottom of the elevator shaft over the governor sheave *H* to the first one of a set of sheaves mounted in a crosshead *C'*, thence to the first one of another similar set of sheaves mounted in a crosshead *C*, thence back and forth over the other sheaves of these sets, and finally over an idler *D* up to the top of the hoistway. The crossheads *C* and *C'* are properly guided and held by springs a certain extreme distance apart under normal conditions. To the crossheads are bolted cast-iron wedges *W*, *W'*, which are so designed as to enter between the rollers *r*, *r* on the ends of the long arms of the levers *L*, *L'*, and thus to push the same apart, closing the grip blocks down on the guide rails. These wedges enter between the rollers when the governor rope is arrested by the gripping device on the governor, since then the two sets of sheaves mounted on the crossheads *C*, *C'* will be pulled together by the rope shortening between them.

10. The action of the governor will be easily understood from Fig. 7 (*b*). The governor rope *x* coming from the governor sheave *H* passes between two jaws *j* and *j'*, the former of which is pivoted to the governor frame and is actuated by a helical spring *t* that gives it a tendency to bear down on the rope against the other jaw *j'*, which is fixed. The movable jaw *j* has an arm *a* attached to it, over which hooks the lug *l* on one end of a double-armed lever or finger *f*. The other end of the lever *f* projects into the paths of the governor weights *w*, *w* so as to be struck

by them when they fly out too much, owing to excessive speed. In this case the lug *l* releases the jaw *j*, the rope *x* is locked to the frame, and the safety is put into action

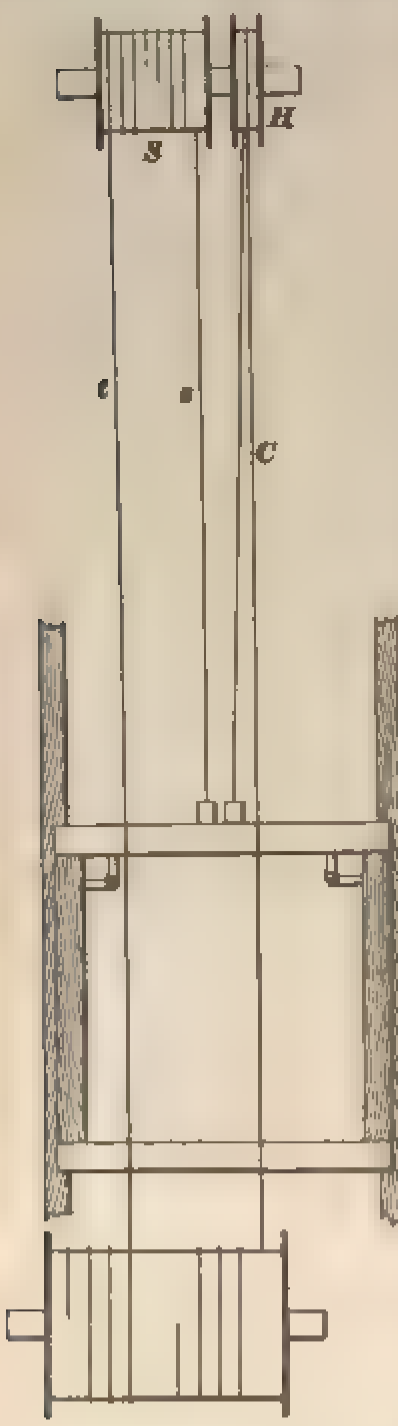


FIG. 8.

SAFETY DRUM.

11. Fig. 8 is a diagram of an arrangement often met with on Otis steam elevators A so-called safety drum *S* is placed on the same shaft as the overhead sheave *H* for the hoisting rope. Attached to this safety drum are two ropes; one, the **safety rope** *s*, runs down to the levers of a suitable car safety on the car, and the other one, *t*, which is wound the reverse way on the drum, runs down to the hoisting drum; this rope is called the **take-up rope.** When the car is ascending, the take-up rope winds the safety rope on the drum *S* If the hoisting cable *C* should break, the weight of the car would come on the safety rope and thus throw the car safety into action. The hoisting rope is generally also connected to an independent car safety.

12. In connection with the safety drum, a governor-controlled brake is generally used, which, if the hoisting rope should break, insures a gradual fall of the car, thus giving the safety time to act without a sudden shock

The governor and brake are shown in diagrammatic form in Fig. 9, where *S* is the safety drum, *B* the brake pulley, and *G* a spur gear driving a pinion *P* From the shaft of this pinion motion is transmitted to the governor spindle by

bevel gears, as shown. The sleeve of the governor operates a bell-crank lever *L* having a projection *l*, on which is supported, by a hook *h*, the brake lever *W*. It is easy to see

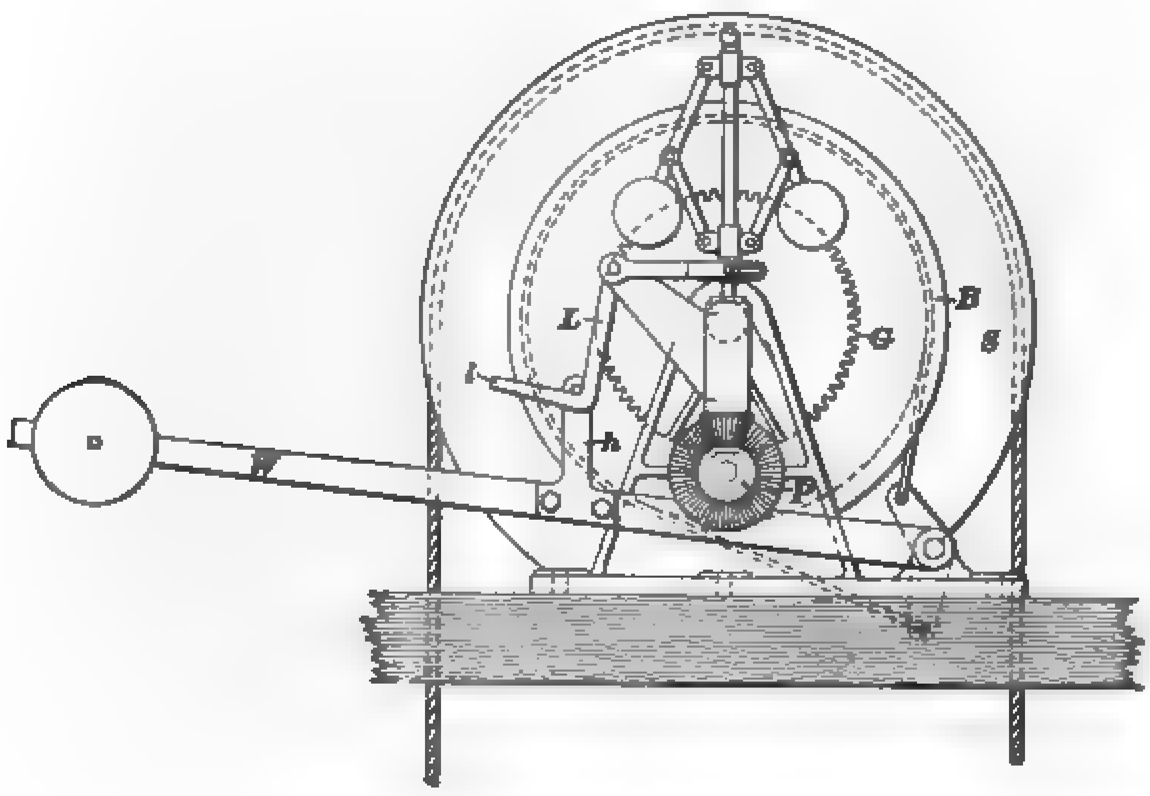


FIG. 9.

that when the governor balls fly out owing to the excessive speed of the car, the arm *l* will pass from under the hook *h*, and the weight on the brake lever *W* will apply the band brake.

13. The different designs of car safeties in actual use are very numerous, but a person understanding the operation of those here described will be able to understand the operation of most of them.

CARE OF CAR SAFETIES AND GUIDES.

14. The importance of keeping car safeties and guides clean and well lubricated, so that they will promptly do their duty when called upon, cannot be emphasized too strongly. Car safeties need adjustment from time to time.

15. When the guide shoes are adjustable, as most of them are, they should be so adjusted that the car will not wabble, but they should not be tight enough to bind on the guide rails. With spring-actuated guide shoes, such as are shown in Fig. 7 (*c*), for instance, the proper adjustment is easily accomplished by manipulating the screw bolts *u* in the same manner as the bolts of a stuffingbox.

In the Otis wedge safety shown in Fig. 4, the spring *S* must be just tight enough to prevent the wedge *W* being pulled upwards when the car is descending by the guide rail *A* coming in contact with it. A weakness of the spring *S* frequently causes wedges to rattle. The wedge should move perfectly free and should be frequently examined to see that it does. If, when the safety wedges move freely and the springs *S* are sufficiently tight, the wedges are still thrown into action or rattle when the car descends, the probability is that one of the cables has stretched or is broken. Care must be taken that all cables draw alike; when they do, the equalizing lever *G* should be horizontal, as shown in Fig. 4 (*a*). In this position the setscrews *s*, *s'* should not touch the finger *H*, but should be so adjusted as to touch and move the finger when the lever *G* is tipped a certain amount either way. The governor should not be too sensitive to harmless variations in car speed. For this reason, the governor rope *r* acts on the lever *l* through the intermediary of a spring, as shown in Fig. 3. This spring should be just tight enough to prevent the wedges from rattling when the car is moving at its normal speed, but not tighter, or the usefulness of the governor will be destroyed.

16. Guides should not be allowed to become gummy, for in this condition they are apt to cause much trouble; they frequently cause the safety wedges to stick, to be thrown into action unnecessarily, or, at least, to rattle. The governor should be examined frequently.

17. In case the safety has acted and has stopped the car, it is of the greatest importance to see, before unlocking the safety, that there is no slack in the hoisting cable. If

there is slack, carefully take it up very slowly, reversing the motion of the motor and running it slowly. In hydraulic elevators, this can be done generally by carefully opening the controlling valve; in electric elevators, it is better to turn the worm-shaft by hand. After the slack has been taken up, unlock the safety catches. Most safeties are so arranged that they unlock automatically when the car is moved upwards. Thus, in the Otis gravity-wedge safety the wedges will drop back by gravity. In the safety shown in Fig. 5, the grip roller will readjust itself. In the safety shown in Fig. 7, the governor rope will automatically release itself when the car is going up, but the tripping device must be readjusted by hand. A hole in the car floor is provided for that purpose.

In case the car has been stopped above the top landing, it may become necessary to remove the limit-stop button on the shipper rope, so that the car may be raised high enough to unlock it. If this should prove insufficient, it may even become necessary to raise the car by a tackle.

AIR CUSHIONS.

18. The car safeties treated in Arts. **2** to **17** are designed to act immediately after the slacking or the breaking of a cable, or at the attainment of an excessive car speed. If, when the cable breaks, the car safety should fail to work, owing to neglect or some other cause, the car will drop unretarded to the bottom of the hoistway, causing destruction of property and the probable death of the passengers. An always-ready means of preventing such serious accidents is the **air cushion.** This may be formed by extending the hoistway below the lowest landing in the form of a pit, which has a cross-section at its top somewhat larger than the platform of the car and which gradually tapers towards the bottom to nearly the same cross-section as the platform. When the car falls into this pit, the air within it is compressed and is forced out gradually around the platform of the car, thus letting the car down gradually.

19. Air-cushion pits, in order to be effective, should have a depth equal to one-fifth the whole lift of the car, that is, 20 feet for each 100 feet of hoistway. The walls of the pit must be air-tight, and great care must be used in their construction. Owing to local conditions, it is not always possible to extend the pit far enough below the ground to make it efficient, in which case it may be formed by making the lower part of the hoistway air-tight, say for one or two stories, and providing it with air-tight doors. The engineer in charge of the plant can only see that the pit is not filled with rubbish and when there any doors that they close air-tight.

ACCESSORIES.

SAFETY APPLIANCES.

ELEVATOR ENCLOSURES.

20. The question of **elevator enclosures** is largely a matter of city ordinances. In general, it may be said that every possible means should be taken to prevent accident to passengers on the elevator, as well as persons whose duty brings them near elevator shafts and hatchways. Whatever means are taken by the builders, either of their own account or in compliance with city ordinances, it is the duty of the engineer in charge to see to it that all enclosures are kept in proper condition. He should be constantly on the lookout for improvements in this line.

Whenever possible, elevator enclosures should extend from floor to ceiling, to prevent anything that is being carried on the car catching between its platform and the ceiling. No projections whatever should extend into the hoistway. If full enclosures are not practicable and goods are carried that are liable to stick out, such as rods and similar articles, a car should be used that is enclosed on at least three sides.

Full enclosures need not necessarily be solid walls or partitions, but can be made of lattice, or grille, work substantially braced. As a matter of fact, solid walls for elevator shafts, while recommended by some engineers, are of doubtful value. An elevator shaft so constructed will act, in case of fire, as a chimney, and will carry the flames from one floor to another. Besides, such shafts are apt to be dark unless windows are arranged in them, which make the shaft more dangerous in case of fire. The windows in such shafts should be securely fastened and preferably covered with wire screens. Latticework enclosures will admit plenty of light. In case enclosures are not carried up to the ceiling, they should be at least 5 feet high. Many an accident has occurred by people bending over too low enclosures to look for the car, which then struck them while coming down. Passenger-elevator enclosures are usually made of artistically formed wrought iron and are intended as an ornament to the building in addition to their usefulness. They are generally expensively varnished and should, therefore, be treated with care. They should be cleaned with a feather duster and soft rags. The use of gritty substances, soap, or oil should be avoided. They should be revarnished from time to time, especially after repairs have been made.

ELEVATOR DOORS.

21. Requirements.—Elevator doors should always be, if possible, sliding doors or gates so hung that they will operate very freely. They should be provided with latches or locks that can be opened only from the *inside* of the shaft, but they should open easily; that is, without requiring much exertion on the part of the operator. Self-closing doors are to be preferred. The operator should not, however, rely on these self-closing devices, but should always make sure that the door is closed before he leaves the landing with his car. He will and should be held strictly responsible for accidents due to doors having been left open.

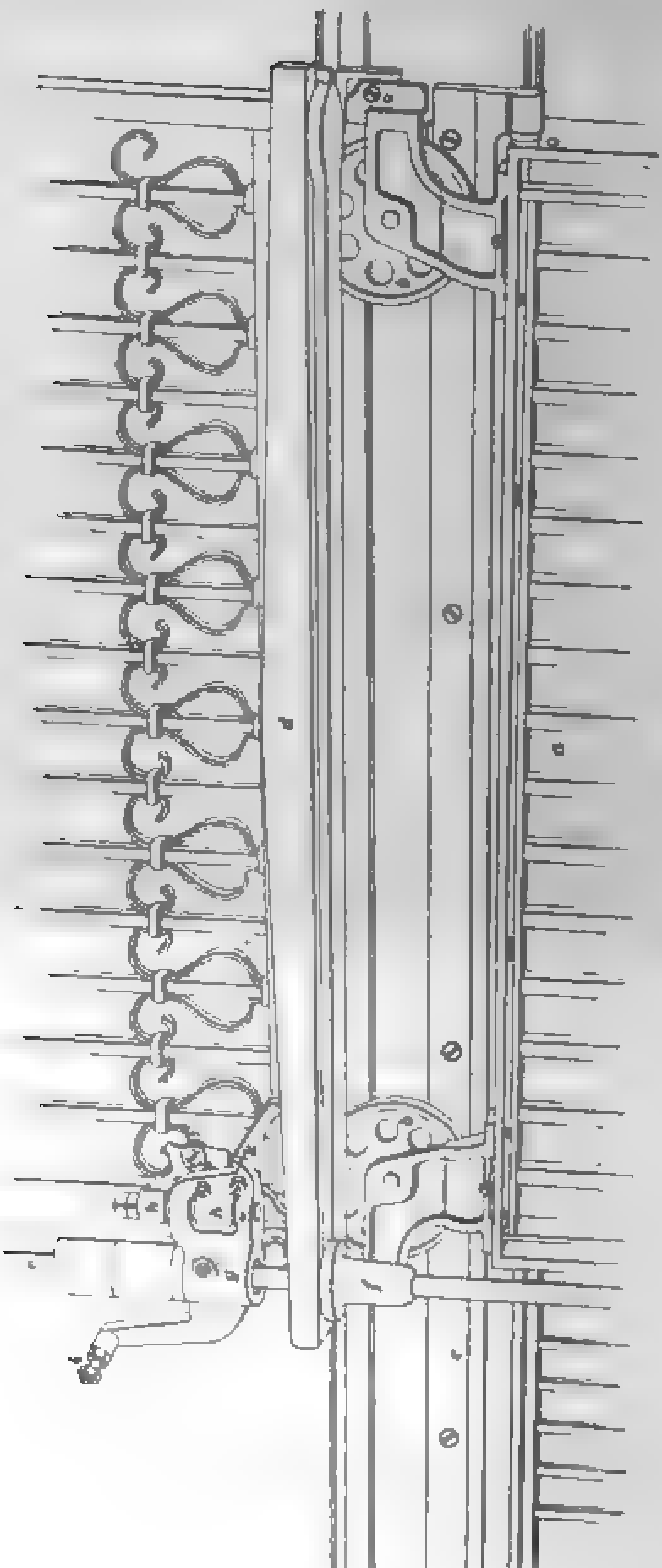


FIG. 10.

22. Self-Opening and Self-Closing Elevator Doors. Various devices are used by different manufacturers to make an elevator door self-opening and self-closing. These devices, in general, have for their object the automatic closing and locking of the door immediately upon the elevator car leaving a landing, and, in addition, are so designed that the operator can open or close the door at will without touching it while the car is at one of its landings and at rest.

23. The elevator-door operating device made by the Winslow Brothers Company, Chicago, Illinois, is shown in Fig. 10. The operation of this device is purely mechanical, the door being moved either way by a friction cone engaging either side of a suitable bar rigidly connected to the door. The construction of the device is as follows: The door *a* is supported by rollers *b*, *b* upon a level track *c* having a **V** groove planed in it to receive the **V**-shaped rollers. This arrangement prevents any side motion of the door. The so-called **traction plane** *d* is rigidly attached to the two door hangers that carry the rollers. A vertical shaft *e* carrying a friction cone *f* and also a cone-operating device at the top of each landing extends from the top to the bottom of the elevator shaft and is continually revolved by a small electric motor, or from some other source of power by belting. The so-called swing bar *g* is pivoted to a bracket *h* that is rigidly fastened to the transom above the door; the swing bar carries a bushing so fitted as to allow it to swing a little. The revolving shaft *e*, which owing to its length is quite flexible, passes through the bushing of the swing bar, the said bushing forming a journal for the shaft. The free end of the swing bar carries the adjustable buffer *i* intended to come in contact with a vertical shoe placed on top of the car. This vertical shoe can be thrown forwards so as to press against the buffer, and hence can be made to swing the swing bar around its pivot by a treadle in the car operated by the foot of the operator.

The traction plane is slotted, the slot being beveled and wider at the bottom; by pressing the buffer *i* away from the

car the friction cone will be pressed against the side of the slot nearest the transom and the revolving cone will thus open the door

As soon as the operator removes his foot from the treadle, the shoe on the top of the car will move away from the buffer *t* and the shaft will spring back, bringing the friction cone against that side of the slot in the traction plane that is farthest from the transom, the revolving cone will then, by its friction against the surface with which it engages, cause the door to close

As has just been explained, the door closes whenever the shoe on the top of the car is moved out of contact with the buffer *t* This shoe is quite short, consequently, should the operator forget to remove his foot from the treadle in the car when starting the elevator, the movement of the car will very quickly take the shoe vertically out of engagement with the buffer *t*; the revolving shaft *e* will then immediately spring back to its normal position and the door will be closed automatically.

The door is held open automatically while the car is at a landing by virtue of a recess in the end of the traction plane into which the friction cone passes after opening the door The door after closing is locked automatically by a catch *k*

24. The Burdett-Rowntree Manufacturing Company use a horizontal pneumatic ram at each landing to automatically open and close the door. The piston of the ram is attached by a link to a long swinging lever connected to the door, and as the ram piston moves one way or the other it carries the door with it. The device is so designed that the door is always held closed until the car is at a landing, when the operator, by pressing on a treadle, throws a movable vertical shoe against a suitable part of the valve gear This operation unlocks the door and admits air under pressure to one side of the piston in the ram cylinder, at the same time opening the other side to the exhaust The door now opens, and when wide open can be kept so by a finger lock as long as the car is at rest. Whenever the operator

removes his foot from the treadle, or unlocks the finger lock, or starts the car either way without having closed the door, the door closes automatically by reason of the valve gear operated by the shoe on the car returning immediately to its normal position.

25. Car-Locking Device.—With elevator doors that are operated directly by hand by the operator, a **car-locking** device is sometimes used that automatically holds the car in position at its landings and only releases the car when the door is fully closed. While such devices are called car-locking devices, it must not be inferred that they lock the car itself to the landings or to the guides; instead they lock the operating device in the car so that the operator cannot move it to start the car in case the door has been left open.

26. Fig. 11 shows the car-locking device designed by Messrs. I. S. Muckle and W. H. B. Teamer. In Fig. 11 (*a*), the car A is shown at one of its landings and at rest, in which position the operating device F occupies its central position. The door D is unlatched and opened, as shown in Fig. 11 (*b*) and (*c*); the operating device in the car is then locked.

The following description of the device is partially taken from the patent specifications: Secured to one of the floor-beams within the elevator well is a spring latch E, which is bent as shown in Fig. 11 (*a*), and extends up into the path of an arm d secured to the door D. This arm is notched at d_1 to receive the spring latch E when the door is closed. When the latch is in the notch of the arm of the door, the latter cannot be moved until the latch is pushed out of the notch by the mechanism carried by the car; the door will then be free to be opened.

A pinion f_2 is keyed to the shaft f_1 of the operating device in the car and meshes with a gear f_3 turning on the stud f_4. A crankpin on this gear f_3 is connected by a rod f_5 to the lever f_6 pivoted at f_7 to a bracket a_1 fastened to the bottom of the car. A bearing a_2 on the bottom of the car carries a

slide A_1, and this slide is connected to the lever f_2 by a rod a_1. It is readily seen that, by virtue of the manner in which the parts are connected, the slide A_1 will be in its extreme outer position when the operating device is in its central position, as shown in Fig. 11 (*a*). The slide A_1 carries a roller a_4 that engages with the spring latch E and forces it out of the notch d_1 of the arm d carried by the sliding door, releasing the latter.

It is seen from the above description that the combination of the slide A_1 with the operating device constitutes a mechanism adapted to release the sliding door whenever the operating device is moved to stop the car, that is, is moved to its central position.

It will now be shown how the operating device is rendered inoperative, i. e., how the operator is prevented from starting the car while the door is open. On the face of the elevator well, to one side of the spring latch E, is a plate G carrying a stud g on which is hung a three-armed lever. The arm g_1 of this lever extends in the path of an arm d_2 depending from the door, so that the opening of the door allows the lever, under the influence of the weight g_3, to turn to the position shown in Fig 11 (*b*). In this position the arm g_2 of the lever has passed behind a flange a_2 of the slide A_1 and prevents the slide from being drawn towards the car. Consequently, the operator cannot move his operating device to start the car, since this can only be moved when the slide A_1 is free. On closing the door, the dependent arm d_2 of the door engages the arm g_1 and turning the lever about its fulcrum g moves the arm g_2 out of the way of the flange on A_1, thus unlocking the slide and hence the operating device.

TRAP DOORS.

In many instances it is impractical to erect enclosures
...d, as, for instance, when the elevator is located in
a warehouse and must be accessible from all
... a case, the holes in the floors through which

the car passes must be kept covered and must be uncovered only to let the car pass. This is best done automatically in some such manner as is shown in Fig. 12. The car is provided

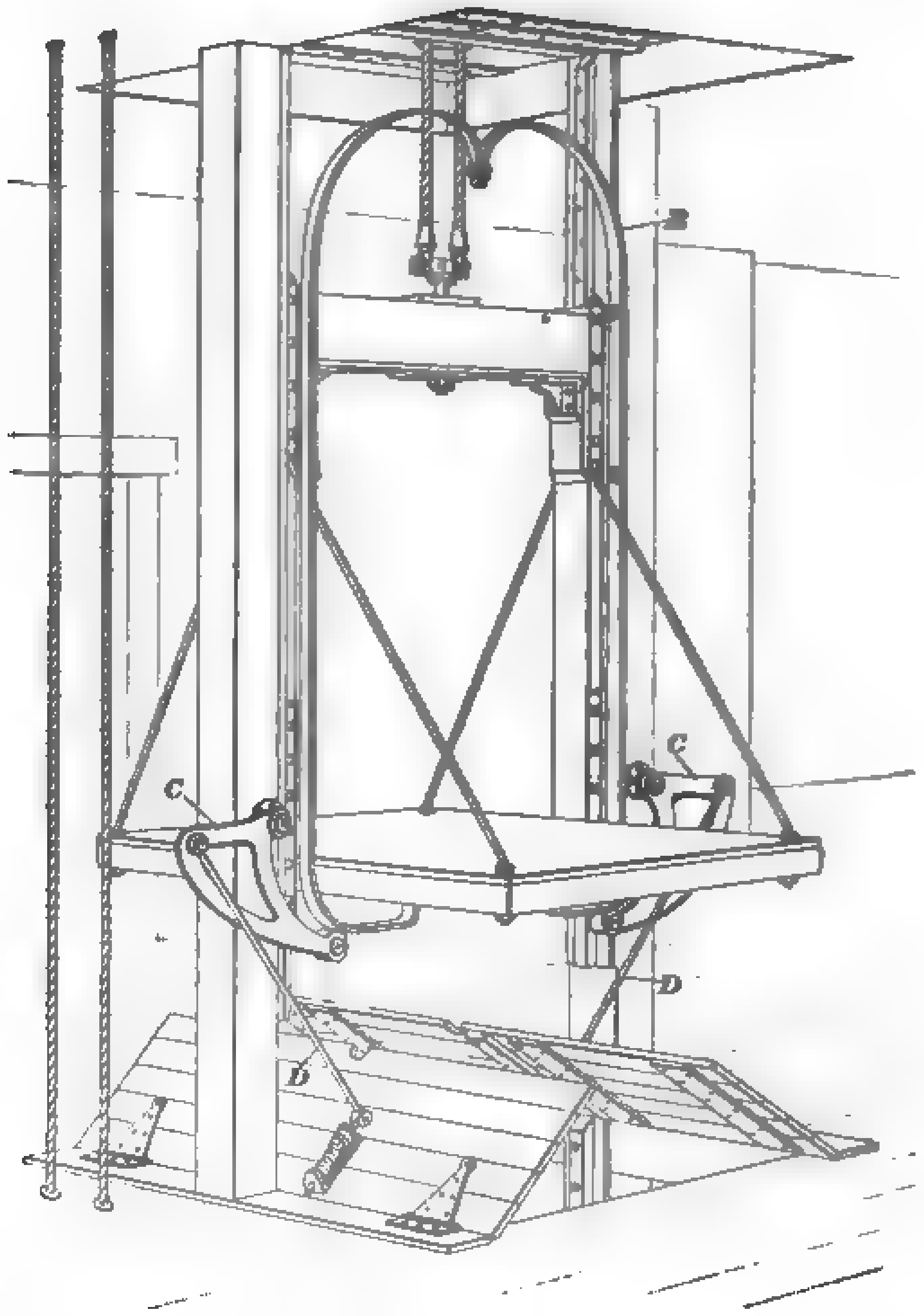


FIG. 12.

with an iron rail *R*. The arch-shaped upper part of this rail gradually opens the trap doors when the car ascends, and the curvature of the under part lets them down gently when

the car descends. To open the trap doors when the car descends, the rail *R* strikes with its lower portion bell-cranks *C*, *C* that are suitably connected to the door by rods *D*, *D*.

INDICATORS AND SIGNALS.

INTRODUCTION.

28. Signals must be considered in many cases as a necessary element of safety, especially in freight elevators with insufficient enclosures or trap-door elevators. Electric bells, one on each floor, so arranged that they commence and continue to ring while the elevator passes the floor, are excellent safeguards; they not only warn persons against the approaching car, but tend towards the prevention of any attempt being made to operate the elevator from two floors at the same time.

29. For passenger service, a signal is necessary to communicate with the operator in the car from each floor. This is done very simply by means of a so-called **annunciator** placed in the car and a push button on each floor near the elevator door. Where the traffic is but slight, this means of communication is satisfactory enough; but where the service is rapid, it proves insufficient. Generally in such cases there are, at least, two elevators running all the time, one going up, the other down, and the would-be passenger should know which one to signal. For this purpose, so-called **indicators** have been devised, which show on each floor simultaneously the whereabouts of the car and whether it is going up or down.

MECHANICAL INDICATOR.

30. A simple mechanical device of this kind is shown in Fig. 13. On the shaft *A* of the overhead sheave is mounted a worm *D* meshing with a worm-wheel *E* that is mounted on a shaft *F*. This shaft carries a chain wheel *I*, from

which motion is transferred by a chain *N* and rods *T* down the elevator shaft to each floor. The rods *T* are guided in plates *W*, one on each floor, and carry arms *Z*, *Z*. From these arms cords are carried over idlers *X*, *X* mounted on the

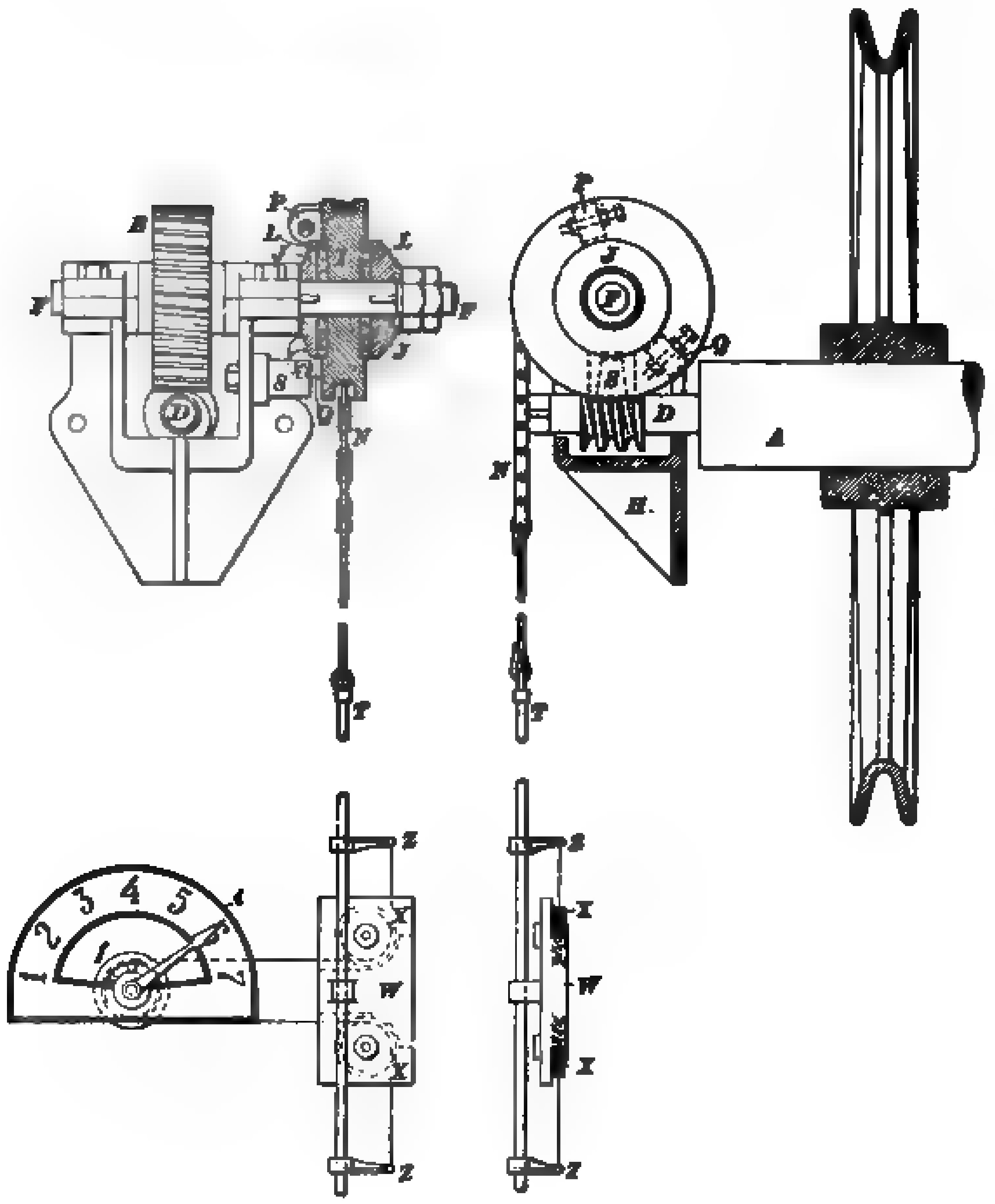


FIG. 13.

plates *W* and around small sheaves *f* in dial plates *i* attached at conspicuous places near the elevator doors. It will be understood that as the car travels up or down, the dial hand will move over the figures displayed on the dial and thus

indicate the position of the car. The apparatus is made self-adjusting to rectify any disarrangement due to slipping of the chain.

The wheel *I* only makes a part of a revolution. It is provided with lugs *P* and *Q* that strike a stop *S* fixed to the frame of the machine as the car reaches its uppermost or lowermost positions, respectively. In case the apparatus has become deranged and indicates wrong, the one or the other of the lugs *P*, *Q* will strike the stop *S* before the car reaches its extreme point of travel and will bring the chain wheel *I* to a stop. On the return trip, the apparatus will then be readjusted. The chain wheel proper is mounted loosely on its shaft *F* and is clamped thereto by friction disks *J*, *J* fast to the shaft and leather washers *L*, *L*.

ELECTRIC SIGNALS AND INDICATORS.

31. The enormous traffic that has to be handled in the large office buildings has called for still more elaborate means of signalling than those afforded by annunciators and indicator dials. In such buildings the service is practically continuous and very swift; the operator has no time to consult an annunciator to find out on which floor passengers are waiting. On the other hand, a passenger standing in front of a row of swift-running elevators and wishing to get the next car would have, if he were to consult indicator dials, to patrol up and down in front of the elevator doors, and would be likely to miss several cars running in the direction in which he wants to go.

32. The usual plan followed in such cases is to provide a signal which, when operated by the passenger, will be noticed by the operator on every car of the series early enough for him to stop at the particular floor where the signal was given. The first car conductor answering the signal then destroys all the signals in the other cars. This plan has been successfully carried out in the Armstrong system, handled by the Elevator Supply and Repair Company, of

New York. This system operates as follows: There are several push-button plates of two buttons, the one marked *up* and the other *down*, conveniently located on each floor. Over each elevator door is a double-light electric lantern, one light marked *up* and the other *down*. A passenger desiring to signal the first car of a bank of elevators, pushes either the "up" or "down" button. This sets the signal, and when the first car moving in the direction the passenger wishes to go reaches a point about three floors distant from that on which he is standing, the lamp in the "up" or "down" compartment of the signal lantern on the outside of the elevator enclosure is automatically illuminated. When the first car approaching the waiting passenger going in the direction he wishes, either up or down, reaches a point about one floor distant, the "operator's signal" is flashed, giving him ample time to stop his car before running past the floor. The operator's signal is a small lamp inside the car constantly in sight. The lamps in both the lantern and car fixture remain illuminated until the car has left the floor from which the signal was given.

There can be no confusion of signals, because the operator can never have but one signal at a time. Moreover, the system is entirely automatic. It allows the operator the free use of his hands and he can thus give all his attention to the control of the car and the safety of his passengers. When no signal light appears in the car, the operator can run at full speed, knowing that no passengers are waiting. Should the first car that receives the signal be fully loaded and therefore unable to stop for more passengers, the operator may transfer the signal to the next car by pushing a button.

All this is accomplished by means of so-called commutators, one for each elevator, placed at the top of the shaft and run by a belt or chain from a pulley on the overhead sheave shaft, in connection with a number of electromagnets corresponding to the number of floors in the building. We forego a detailed description of the apparatus and the electrical connections thereof, since once installed, the apparatus

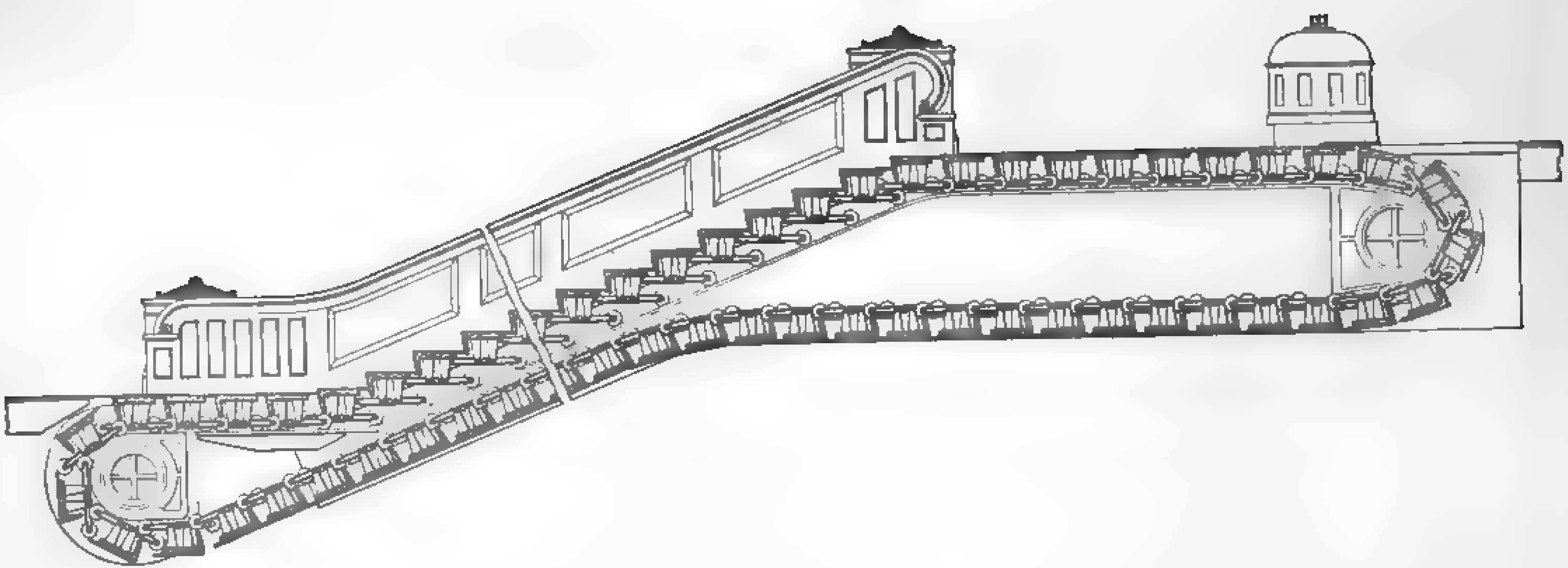


FIG. 14.

needs never to be disturbed. The engineer in charge should see to it that the contacts are kept clean and that the mercury cups used to make the various circuits have the proper amount of mercury. The current for the push-button circuits is furnished by a small motor-dynamo transforming an ordinary 110-volt lighting circuit to one of about 10 volts. This motor-dynamo, of course, needs an occasional inspection, just the same as the other machinery. The current for the lanterns is taken from the lighting circuit direct.

ESCALATORS.

33. The name **escalators** has of late appeared in the terminology of elevator practice for what are commonly known as **moving stairways.** These moving stairways are, properly, not to be classed among elevators, being constructed upon entirely different principles and are mentioned here only for sake of completeness and for the reason that they are destined to take the place of elevators in many instances. Thus it has been found that for short lifts, say one or two stories high, and where great numbers of people are to be transported, that adequate elevator capacity can be had only at great expense and sacrifice of floor space out of keeping with the profits accruing therefrom.

The moving stairway consists of an endless chain, to which are attached steps in such a manner that they form steps like those of an ordinary stairway. By an arrangement of cams, guide rails, and rollers these steps form a plane surface at the bottom and top landing. The accompanying sketch, Fig. 14, will convey the idea. It represents one of the latest designs of this class of passenger-transportation machinery built by the Otis Elevator Company, New York.

STEAM HEATING.

INTRODUCTION.

DEFINITIONS.

1. Although steam fitting is a distinct trade by itself, engineers are sometimes called upon to do such work, and are often required to attend to, and to be responsible for, steam-heating plants.

The following brief explanation of technical terms used in connection with systems of piping for steam distribution to radiators and heating coils will help to make the text matter clear.

2. A **steam main** is the pipe that conveys steam from the boiler or other source of supply and distributes it to the several branches. It is usually run along the cellar ceiling, being hung from the first-floor beams by adjustable iron hangers. It pitches down from its highest point near the boiler to its lowest point at the farther end of the main. The pitch should be at least ¼ inch in 10 feet, so that the water of condensation may freely flow to the lower end of the main.

An **overhead main** is a steam main that is run horizontally, or nearly so, at an elevation higher than the radiators that it supplies. This is supplied from the boiler by a vertical **rising main.**

3. **Risers** are the vertical pipes that rise from floor to floor to convey steam from the steam main to the radiators

or coils on the several floors. **Drop risers** are those in which the steam flows downwards to the radiators or coils from a steam main above, usually in the attic.

4. Riser connections are the pipes, usually short and nearly horizontal, that connect the steam main to the lower ends of the risers or an overhead main to the upper ends of drop risers.

5. Radiator connections are the pipes that connect the radiators to the risers or mains; they are usually short and seldom larger than 2-inch pipe.

6. A **return main** is a nearly horizontal line of pipe, usually run near or under the cellar floor; it receives all water of condensation from the heating system and returns it to the boiler or otherwise disposes of it.

7. Return risers are those vertical pipes that take the water of condensation from the radiators or coils on the several floors of a building and convey it to the return main.

8. A **drip pipe, relief,** or **bleeder** is a small pipe used to drain water of condensation away from a low point, "pocket," or "trap" in the steam pipes.

9. A **dry return main** is one that is run above the water-line of the boiler and, consequently, is partly filled with steam.

10. A **wet return main** is one that is run below the water-line and is filled with water at all times. As a rule, this is more reliable than a dry return main except in places where the main is subject to frost.

11. Coils are a number of pipes stacked together for the purpose of giving off heat to the air around them.

12. Direct radiation is a term applied to all kinds of coils and radiators that are placed inside the rooms to be heated. This is the most common practice in heating

ordinary buildings because of its cheapness, effectiveness, and simplicity.

13. **Indirect radiation** is a term applied to all kinds of coils, radiators, and other forms of heating surfaces that are located outside the rooms to be warmed. Indirect radiators are usually hung from the cellar ceiling, are encased with a galvanized sheet-iron jacket, and are so constructed that fresh air from the outer atmosphere flows between the heating surfaces and enters the room, thus providing ventilation as well as heat. The radiator itself, however, is concealed from view.

14. **Direct-indirect radiation,** sometimes called **semi-direct,** is a term applied to all kinds of radiators and coils that are located in the rooms to be warmed and are provided with means for fresh air to enter through them to the rooms from the outer atmosphere.

METHODS OF HEATING BY STEAM.

CLASSIFICATION.

15. The various systems of heating by steam may be classed in a general way as (1) *high-pressure systems;* (2) *low-pressure systems;* (3) *vacuum*, or *exhaust*, *systems.*

In the first class are all systems of heating that work on a pressure greater than 10 pounds by the gauge; in the second class are those that work between atmospheric pressure and 10 pounds by the gauge; in the third class are all systems that work at a pressure lower than that of the atmosphere.

Any one of these systems may be subdivided as follows: (1) *The one-pipe system;* (2) *the two-pipe system;* (3) *the two-pipe system with separate return risers;* (4) *the overhead-main* or *drop-supply system.*

These, in turn, may be *gravity-return systems* or *forced-return systems*, and they may have *wet return* or *dry return*

mains. In the **gravity-return system**, the water of condensation flows back to the boiler by gravity. This is used in cases where the full boiler pressure is allowed on the heating system. It cannot be used elsewhere.

The **forced-return system** is that in which the water of condensation is forced back to the boiler from the return mains of the heating system by a pump, steam loop, steam-return trap, or other such contrivance. This is used when the boiler pressure is higher than the pressure in the heating system, as, for example, when a pressure-reducing valve is used on the steam-supply pipe to the heating system.

PIPING SYSTEMS FOR STEAM DISTRIBUTION.

INTRODUCTION.

16. The principal systems of piping that are now in vogue for heating purposes are shown in Figs. 1 to 4. These diagrams are intended to illustrate only the general arrangement of the piping, and many details are, therefore, omitted. The radiators *a*, *b*, *c* are supposed to be located on different floors of a building and at various distances from the vertical supply pipes, or risers. It will be seen by careful inspection of the diagrams that the main difference between the several systems consists in the method of returning the water of condensation to the boiler.

ONE-PIPE SYSTEM.

17. The **one-pipe system** is shown in its simplest form in Fig. 1. Steam flows from the boiler *B* through the riser *s* and is conveyed to the radiators through suitable branches, which are nearly horizontal. All the water of condensation flows backwards through the same pipes, moving in a contrary direction to the steam. All the nearly horizontal pipes,

such as *h* and *e*, must, therefore, be inclined sufficiently to secure the ready movement of the returning water. This is purely a one-pipe system and can only be used on very small jobs.

TWO-PIPE SYSTEM.

18. The **two-pipe system** is illustrated by Fig. 2. Each radiator has two connections, one of which serves as an inlet for steam and the other as an outlet for water. The steam supply passes through the pipes *h* and *s* and the water flows back to the boiler through the return pipes *r* and *f*. The branch *e* that supplies steam to the radiator *b*, at a considerable distance from the riser, is inclined so that the water

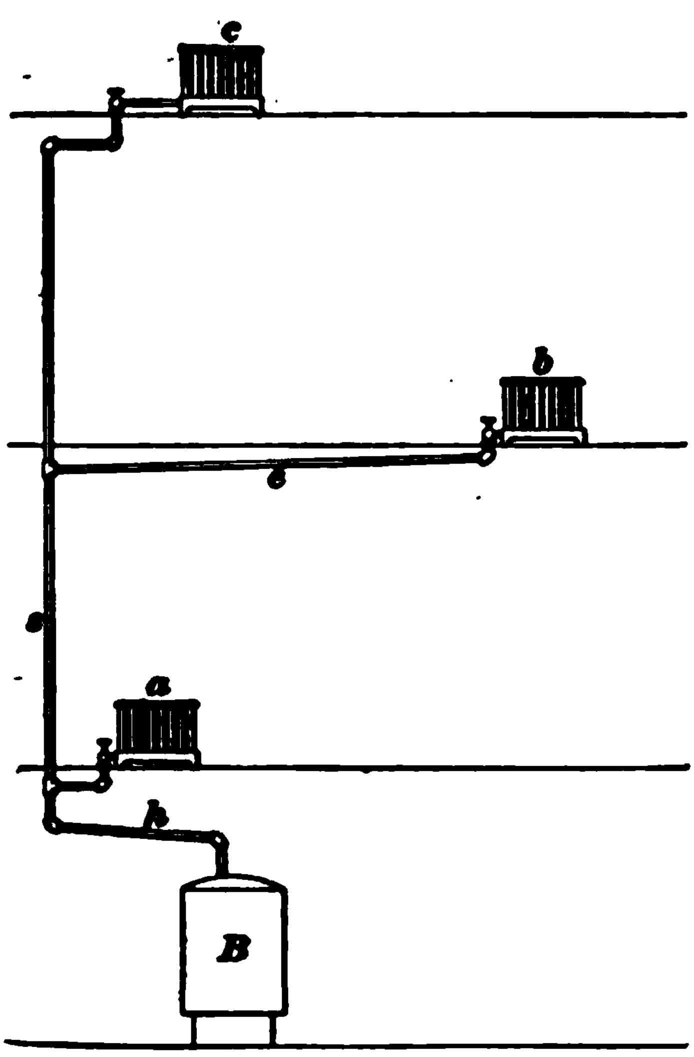


FIG. 1.

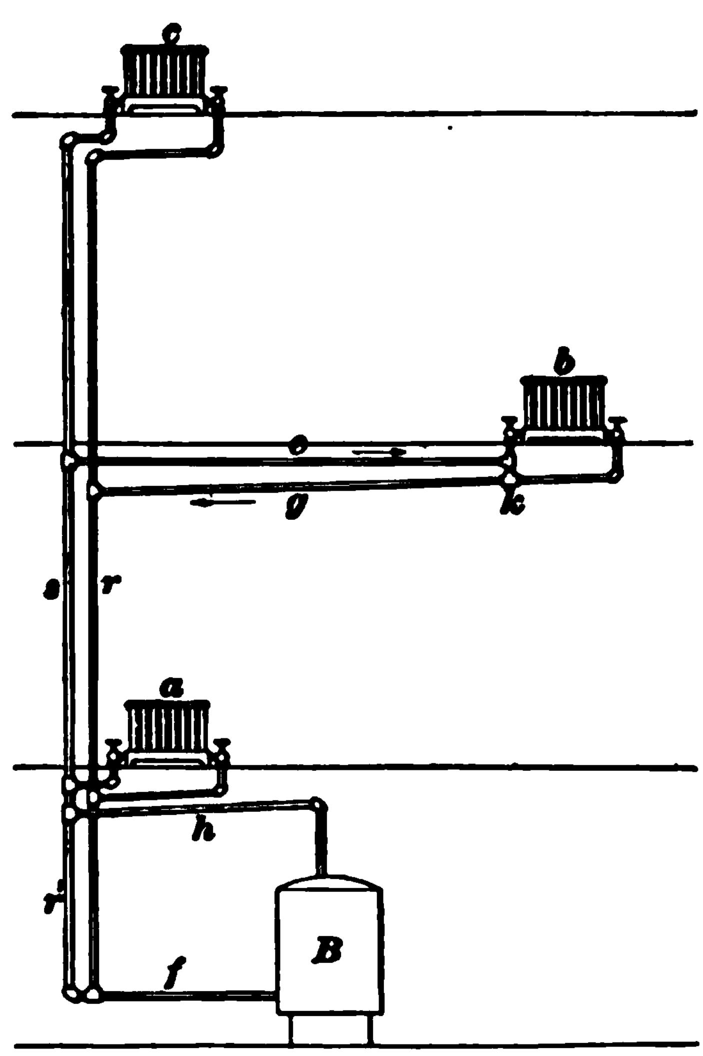


FIG. 2.

formed within it will flow towards the radiator. It is connected at *k* to the return pipe *g* by a small relief pipe, so that the water will be drained off and prevented from entering the radiator. The steam main *h* is also inclined, if it is of any considerable length, so that the water formed within it will run towards the foot of the riser *s*. All the water

formed in the pipes *h* and *s* is drained off by the *relief pipe r′* Thus the steam and the water are carefully separated at all points in the system.

SEPARATE-RETURN SYSTEM.

19. The **separate-return system** is shown in Fig. 3. The steam-supply pipes are the same in every respect as

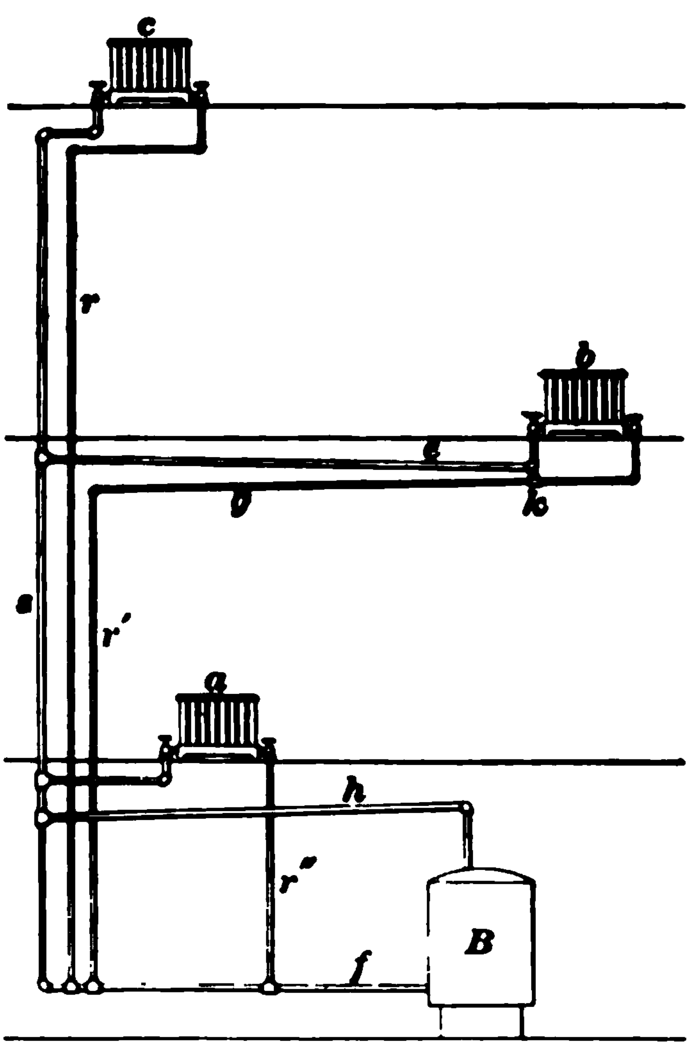


FIG. 3.

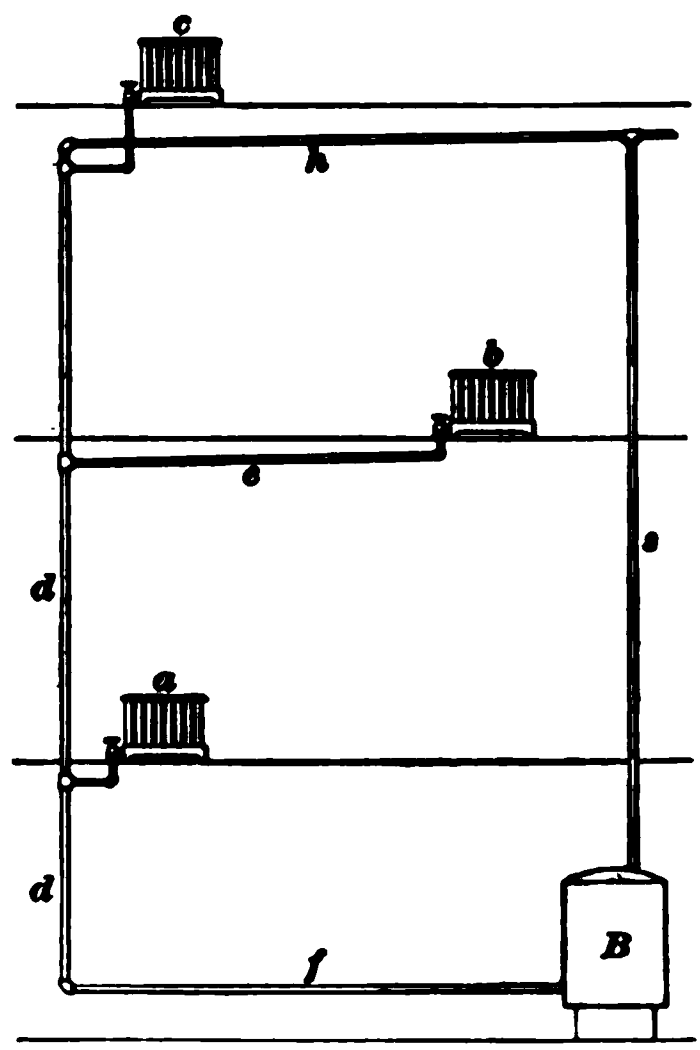


FIG. 4.

in Fig. 2. The returns, however, are different, each radiator being provided with its own separate return pipe, as shown at *r*, *r′*, *r″*.

DROP SYSTEM.

20. The **drop system** is shown in Fig. 4. The steam supply passes up the riser *s* to the top of the system, thence along the horizontal pipe *h*, and descends through the drop pipe *d*. The radiators are connected to the steam supply with single pipes, precisely as in Fig. 1. It will be seen that the water in the pipes *h* and *d* moves in the same direction as the steam, instead of in the opposite direction, as in the

single-pipe system. It is not necessary that the return should be made parallel with the steam-supply pipes, as they are shown in Figs. 2 and 3, but they may follow any convenient route back to the boiler. It is always advisable to make the returns as direct as practicable, care being taken, however, to avoid straggling the pipes about the building in an unsightly fashion.

CIRCULATION.

21. The "circulation," that is, the supply of steam, is far more certain in the two-pipe system than in the one-pipe system, because there is nothing to oppose or interfere with it at any time. Thus, a radiator at the end of a long horizontal branch, as at *b* in Fig. 1, is liable to have its supply interrupted by the formation of the returning water into "slugs," filling the bore of the pipe and causing **water hammer**; but when the pipes are arranged as in Fig. 2, the same formation may happen without causing any trouble whatever.

When steam and water flow in the same pipe, the steam is likely to be wet, because the separation is less complete than when they are kept apart. When the currents flow in contrary directions, the wetness of the steam is aggravated, and there is such an amount of mechanical interference between them that larger pipes are required than would otherwise be necessary, and there is also much greater liability to water hammer and sizzling noises.

COMPARISON OF SYSTEMS.

22. Occasionally a radiator will gradually fill up with water. This occurs in a one-pipe system when the steam valve remains nearly closed for a considerable time, but not shut tight. The steam is then condensed as rapidly as it enters, and the opening is so restricted that little water will escape. The same thing will happen in a two-pipe system if either of the valves is closed and the other remains open.

By opening both valves wide the water will almost noiselessly pass out into the return, but in the one-pipe system, as soon as the valve is opened, a violent struggle will begin between the entering steam and the escaping water. The result will be a succession of rumbling, hammering, and snapping noises, which will continue for several minutes. If the supply pipe is long, as at *c* in Fig. 1, the noise is likely to be prolonged to an annoying extent.

23. In a large heating system, the amount of water to be returned to the boiler is so great that it becomes very difficult to pass it through the steam-supply pipes without interfering seriously with the flow of steam to the radiators. The difficulty reaches a maximum in the coldest weather, the greatest amount of condensation occurring at the same time that the largest supply of steam is required. A single-pipe system must be carefully planned to avoid failure at this critical time, and it is good policy to attach returns at some of the principal points to intercept the water and prevent its flooding the riser connections.

The two-pipe system, however, when carried out completely, has a certainty of operation and freedom from noise, which in many cases makes it much superior to the one-pipe system.

SUBDIVISION OF LARGE HEATING SYSTEMS.

24. It is advisable to divide all heating systems that are of any considerable extent into several independent sections. Long or troublesome horizontal branches may be reduced to a minimum by using independent or special risers and carefully locating them where they will supply the largest number of radiators to the best advantage. One riser may be used to supply almost any number of radiators, provided that none of them are located so far away as to make it difficult to drain the supply branch. Thus the question of the number of risers to be used will be determined mainly by considering the drainage in the horizontal pipes.

In a very tall building, a single riser may be sufficient, provided that the floors are of moderate dimensions; but if the building covers a large area of ground, two or more risers will be required. In all cases, however, it is advisable to have the branches as short as possible.

Each section of a heating system should be made *independent* of the others, so that it can be closed down for repairs without affecting any other part of the system. Large straightway or gate valves should be placed close to the mains in both the supply and return riser connections.

DESIGN OF PIPE SYSTEMS.

PRECAUTIONS.

25. In planning any system of steam pipes, there are two things to be kept always in mind and that must be fully provided for; these are **drainage** and the movement of the pipes by **expansion.** No heating can be done without condensation, and the water thus produced must be disposed of promptly and completely and in a manner that will prevent interference with the steam supply.

Expansion and contraction are inevitable, and the movement is repeated every time the system undergoes any considerable change in temperature. This movement must be provided for, otherwise it will break the joints and make serious trouble.

STEAM-MAIN ARRANGEMENT.

26. The general arrangement of a **steam main** to supply several risers is shown in Fig. 5. The boiler *a* is set on the cellar or basement floor and furnishes steam to the entire system. The steam main *b*, whose duty it is to convey steam to the several risers *c*, *c*, through which it flows to the radiators *d*, *d*, etc. placed within the rooms to be warmed, is connected to the steam space of the boiler and is so suspended from the floor joists by hangers that it will have a

uniform fall from its highest point, which is immediately above the boiler, to its lowest point *f*. A pitch of about ¼ inch in 10 feet is usually considered a sufficient fall for the main. When steam is generated in the boiler, it is forced into the steam main, from there into the risers, and thence into the radiators. The air that the pipes contain is forced out of the system to the atmosphere through air vents or small valves placed at suitable points in the system, usually

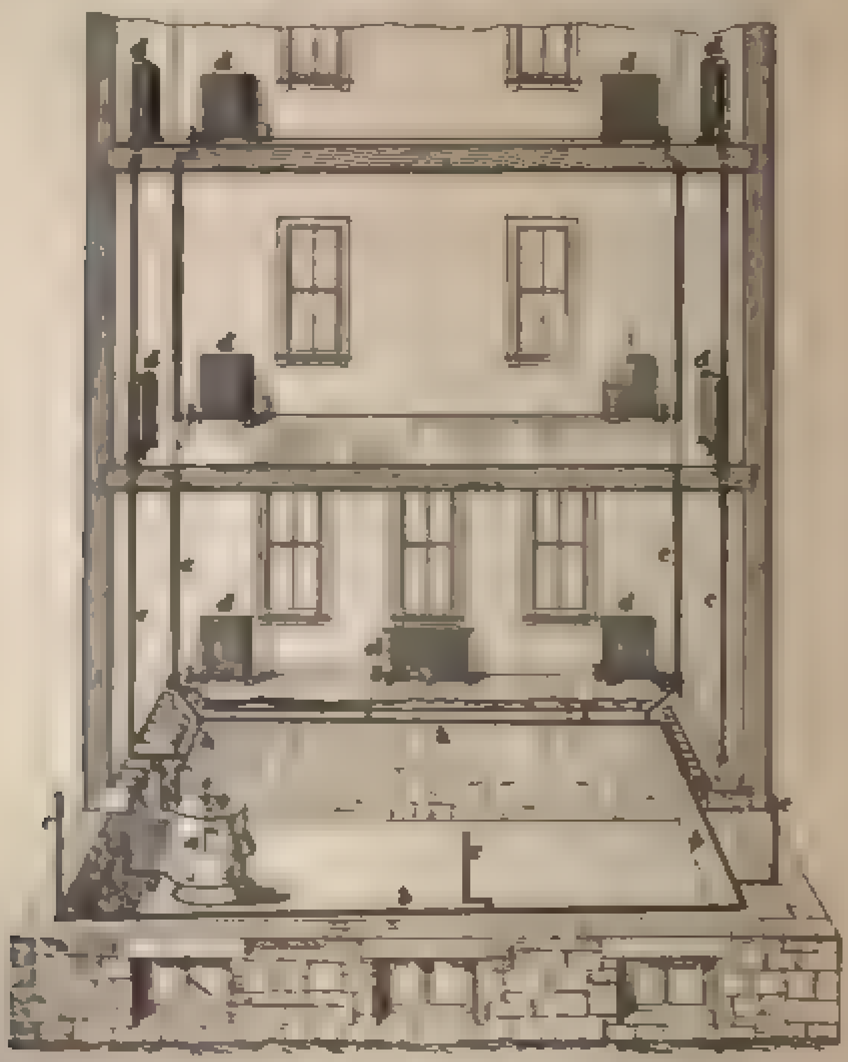


FIG. 3

upon each radiator at the end opposite the steam inlet. As steam flows through the main and the risers, part of it will be condensed by heat being transmitted through the pipes to the air and objects surrounding them. This condensed eam will fall by gravity to the bottom of the steam main, w to its lower end *f*, and enter the bottom of the boiler ough the return pipe *g*. The water of condensation

from the radiators first accumulates in the base of the radiators until a sufficient hydrostatic head is formed to cause it to flow out of the radiators against the inflow of the steam. It then falls down the risers, through the riser connections, and into the steam main, also against the flow of the steam. If the riser connections to the steam main or radiator connections to the riser have too little pitch, or if the pipes are too small, the flow of the water of condensation through them will be resisted by the flow of steam to such an extent that the water will not flow off as quickly as it is formed, the result of which will simply be that the water will accumulate in the pipe until it entirely closes it, when water hammer will take place. The steam main should be made sufficiently large to prevent such a difference between the pressure in the boiler and that at the point *f* as would cause the water to back up in the main and retard the flow of steam to any riser connection.

DETAILS OF PIPING.

27. Connection of Boiler Main.—In many cases it is advisable to connect the steam pipe leading from the boiler to the mains at a point near the middle of their length, as at *a* in Fig 6. The pipes may then be graded downwards from *a* in both directions.

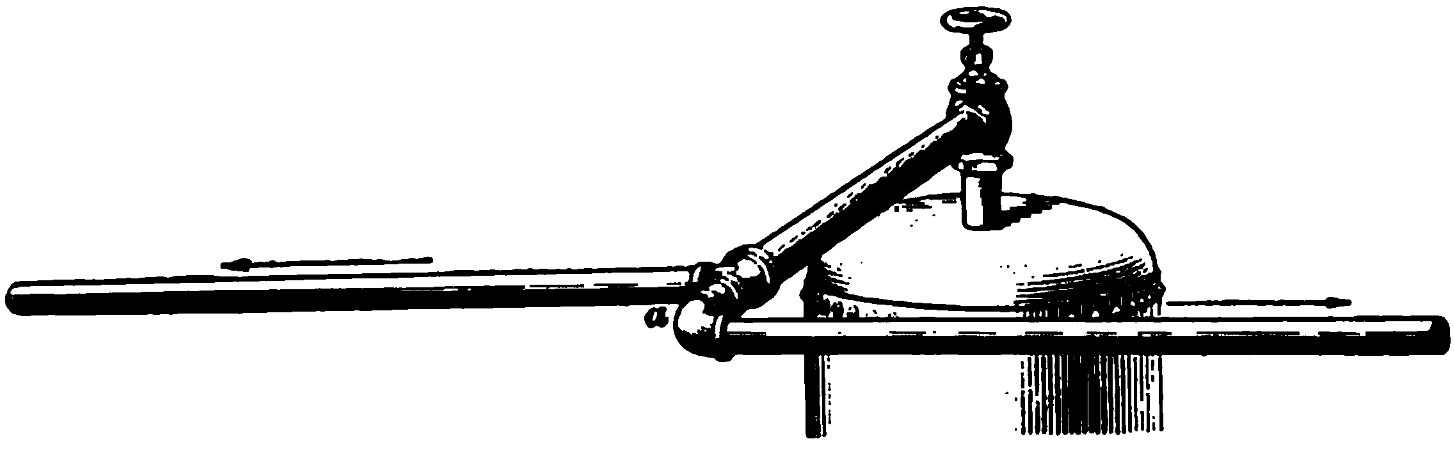


FIG. 6.

28. Relays.—When a main or any horizontal steam-supply pipe has to be run a long distance, it becomes impracticable to grade it uniformly throughout its whole length,

because the far end drops too low to be drained conveniently. In such a case, the difficulty may be overcome by introducing *vertical offsets*, or **relays**, in the line of pipe, as shown in

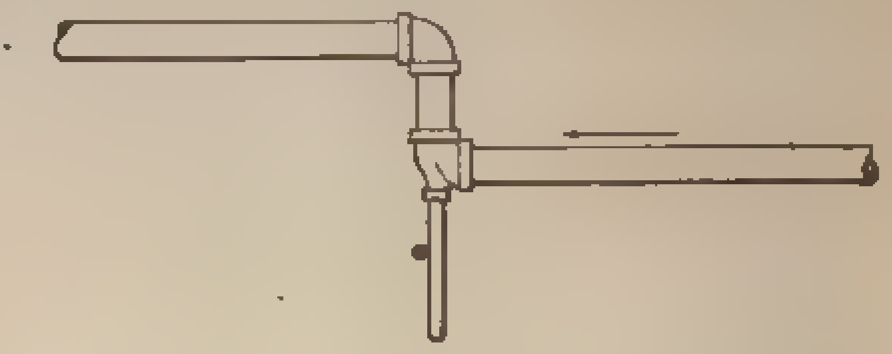


FIG. 7

Fig. 7. A relief pipe may then be attached at the foot of each offset, as at *a*. The steam should always flow down grade—that is, in the direction of the arrow.

29. Riser Connections.—The riser connections in one-pipe systems may be made as shown in Fig. 8 or 9. They permit the mains to be kept from the foundation walls sufficiently to allow them to be gotten at conveniently for screwing together and also for putting on coverings, etc.

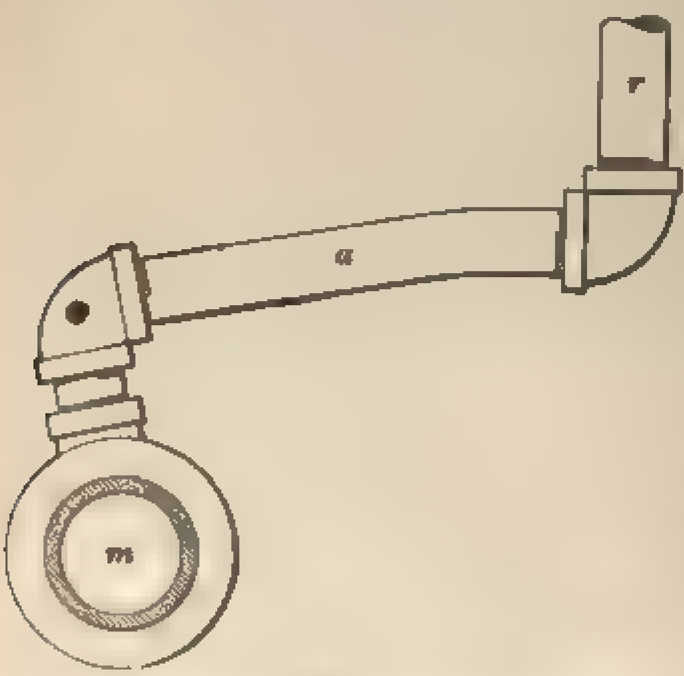


FIG. 8.

The piece *a* serves as a **spring piece**, and permits both the main and the riser to shift slightly by expansion. In Fig. 8 the spring piece is bent, to insure good drainage. The construction shown in Fig. 10 is sometimes used for the same purpose, the grade being secured by cutting the thread crooked at the end *a*. This is bad practice, because the teeth of the dies cut too deeply into the pipe on one side and weaken it seriously.

30. A riser should not be connected directly into the top of the main by a **T**, unless both pipes are very short. If the riser is long, its weight will cause the main to sag, and if the connections to the radiators above are rigid, the downward expansion will either bend the pipe or lift the radiators.

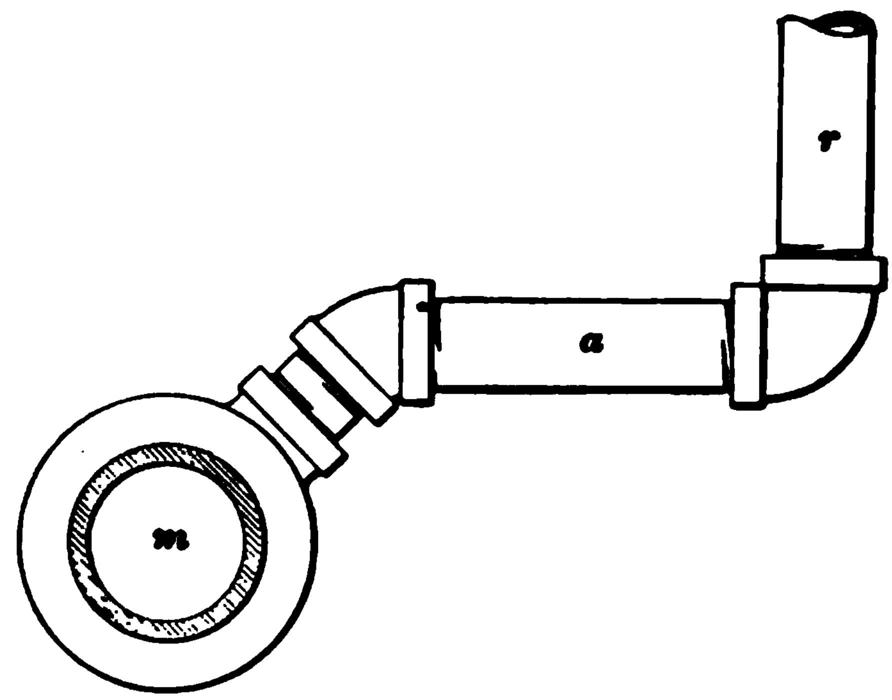


FIG. 9.

The connections to radiator branches, etc. should, if possible, be made with **Y** fittings. Plain **T** connections are objectionable in a one-pipe system, because the water of condensation runs down upon the interior surface of the riser and is very apt to flow outwards into the branch, thus increasing the difficulty of draining it properly.

31. In the case of risers that are very high, provision must be made for expansion. This may be done by making slightly inclined offsets in the pipe, at intervals not greater than two stories apart. If the weight is considerable, the riser must be supported by other means than its connections to horizontal branches.

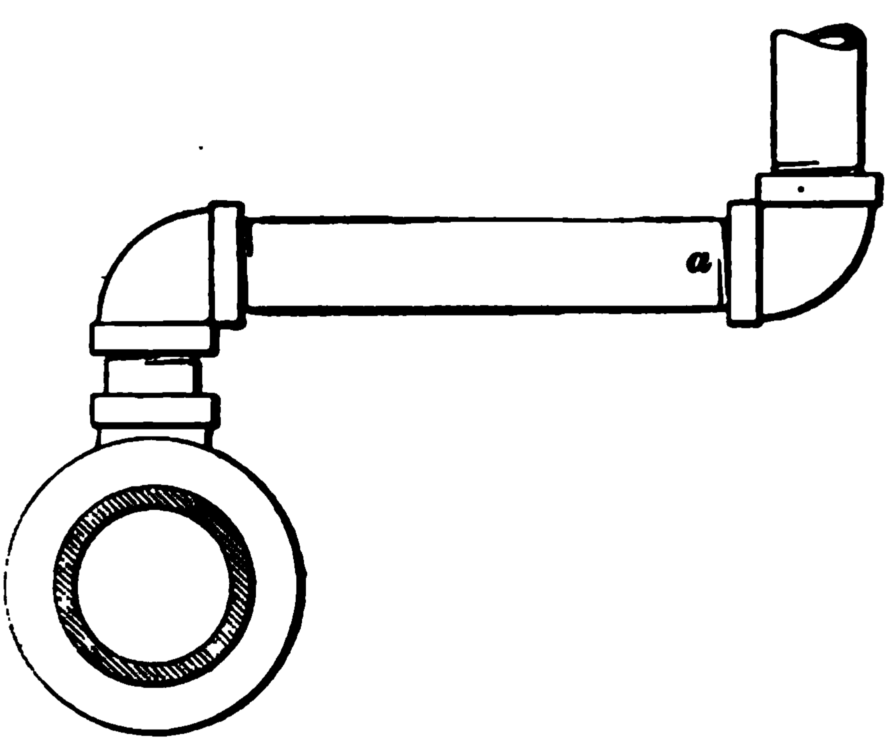


FIG. 10.

32. Radiator Connections.—The ordinary mode of connecting a direct radiator to the riser in a one-pipe system is shown in Fig. 11. The pipe *a* serves as a spring piece to allow the riser to expand without lifting the radiator

and the drop *b* insures that the water shall drain away readily.

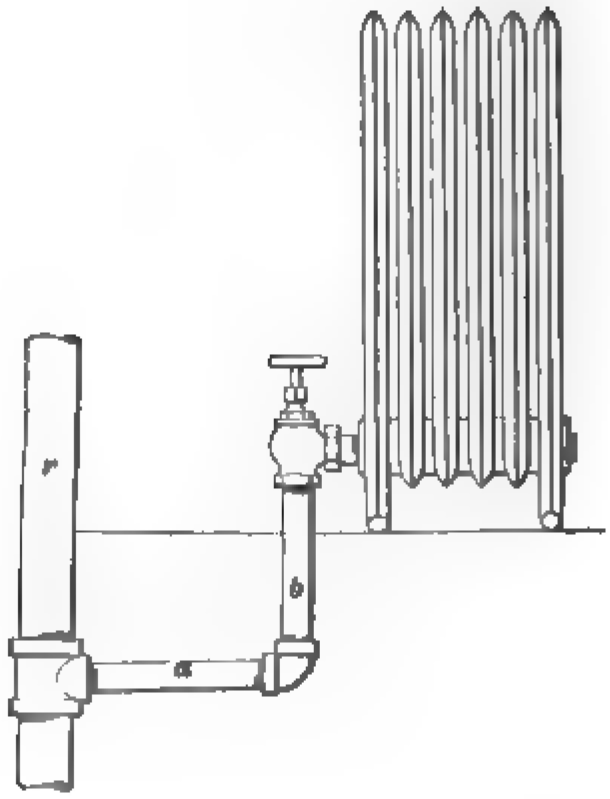


Fig. 11

33. When the radiator is at a long distance from the riser, so that the drainage becomes difficult, it is advisable to put in a double connection, as shown in Fig. 12. The supply pipe *a* and the drain pipe *d* are both connected to the riser *r*, and a siphon is placed at *b*. All the water that flows through *a* will thus pass into the drain pipe without entering the radiator.

34. The connection shown in Fig. 13 permits the radiator to be set very close to the riser, and at the same time the spring piece *a* is so long and flexible that the riser may move considerably

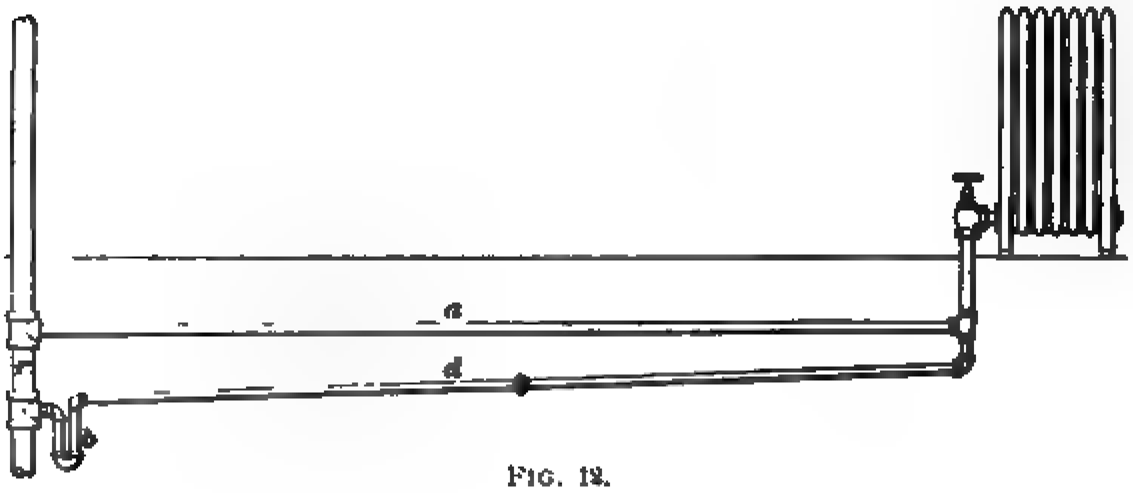


Fig. 12.

without making any trouble. It also has the advantage of being entirely above the floor, so that it is accessible at all times, and the valve is brought out into a convenient position.

35. When the vertical movement of the riser is excess-e, the swivel connection shown in Fig. 14 may be used.

In this form of connection, the pipe *a* may be inclined any amount desired, in order to secure perfect drainage.

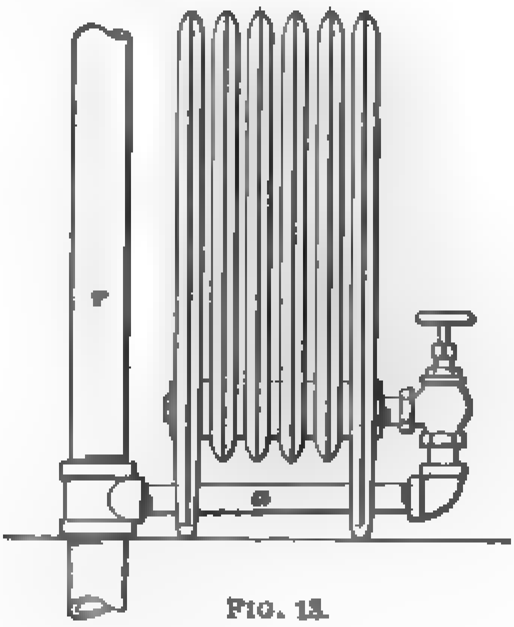


FIG. 13.

36. Returns.—The downward grade given to return pipes should be as nearly uniform as practicable. There should be no upward bends or loops, because air is likely to collect in them and impede the flow of the water. Care must be taken, also, to avoid forming sags or depressions in which water will accumulate.

When the returns are connected to a main that is located above the water level, and if there is any perceptible difference in the pressures at the various radiators thus connected, the steam will flow backwards through the return pipes towards the points of lowest pressure, and in most cases will spoil the drainage and cause water hammer. As the fall of pressure at any radiator is due solely to the resistance that the supply pipes offer the flow of steam, it follows that the trouble in that case may be remedied by increasing the diameter of the supply pipes. It is quite impracticable, however, to connect drain pipes or returns leading from radiators having a considerable difference in pressure with a dry return main.

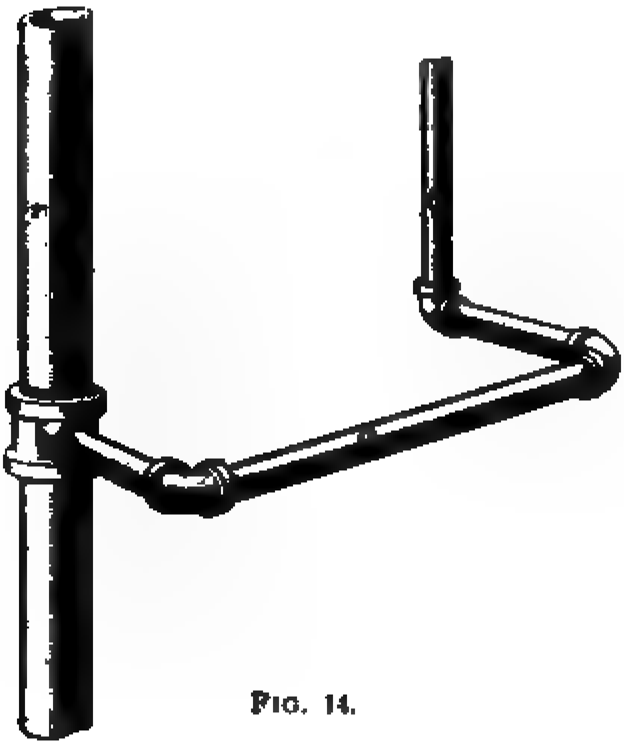


FIG. 14.

37. When the return main is located below the water level, the water that it contains acts as a barrier to prevent

the passage of steam from one return to another. Thus the steam is compelled to pass through the system in the direction it was intended to go, instead of making a short circuit or by-pass This makes a positive circulating job

38. Water Level in Returns.—There is always more or less difference in the pressure of the steam in the boiler and at the end of a line where the return is connected; therefore, the water will rise in the return to a height above the water level in the boiler sufficient to balance the difference in pressure. As this difference varies in the several returns, the water is likely to stand at different heights in each. The hot water rises about 29 inches for each pound of difference in pressure. If there is a water pocket anywhere in the return pipe, the water will back from it towards the radiator until it balances the difference in pressure upon the opposite sides of the water. Thus a radiator that is well above the proper water-line may be flooded with back water if there is a water pocket near it in the return.

39. Size of Pipe Required.—The proper size of pipe is one that will furnish a sufficient amount of steam without undue fall of pressure, and at the same time will not present an unnecessary amount of surface for condensation.

It is found in practice, when steam having a pressure less than 5 pounds is used, that the proper sizes for *branches* to radiators are about as follows:

TABLE I.

PROPER SIZES OF BRANCH PIPES FOR ONE-PIPE SYSTEM.

Heating Surface of Radiators.	Diameter of Pipe. Inches.
24 square feet or less	1
Above 24 and not exceeding 60 square feet	$1\frac{1}{4}$
Above 60 and not exceeding 100 square feet	$1\frac{1}{2}$
Above 100 square feet	2

TABLE II.

PROPER SIZES OF BRANCH PIPES FOR TWO-PIPE SYSTEM.

Heating Surface of Radiators.	Diameter of Steam Pipe. Inches.	Diameter of Return Pipe. Inches.
48 square feet or less..................	1	$\frac{3}{4}$
Above 48 and not exceeding 96 square feet	$1\frac{1}{4}$	1
Above 96 square feet	$1\frac{1}{2}$	$1\frac{1}{4}$

40. These data are for *direct* radiators, and if indirect radiators, which condense more steam per square foot, are used, the size of the pipes should be increased. The proper sizes are given in the following table:

TABLE III.

PROPER SIZES OF BRANCH PIPES FOR SYSTEMS WITH INDIRECT RADIATORS.

Heating Surface of Indirect Radiators.	Diameter of Steam Pipe. Inches.	Diameter of Return Pipe. Inches.
30 square feet or less....................	1	$\frac{3}{4}$
Above 30 and not exceeding 50 square feet	$1\frac{1}{4}$	1
Above 50 and not exceeding 100 square feet	$1\frac{1}{2}$	$1\frac{1}{4}$
Above 100 and not exceeding 160 square feet	2	$1\frac{1}{2}$

41. The size of **steam mains** or of **principal risers** may be computed by the following rule:

Rule 1.—*Divide the amount of direct heating surface in square feet by 100; divide the quotient by .7854; then extract the square root of the quotient; the result will be the diameter of the pipe in inches.*

EXAMPLE.—What diameter of main steam pipe is required to supply direct radiators having a total heating surface of 3,800 square feet?

SOLUTION.— $\sqrt{\frac{3,800}{100} \div .7854} = 6.9$ inches; or, in practice, 7-inch pipe. Ans.

42. To find the amount of radiator surface that may be properly supplied by any given size of pipe, the reverse process should be followed:

Rule 2.—*Multiply the square of the diameter of the pipe in inches by .7854; then multiply the result by 100; the result is the total amount of heating surface in square feet which the pipe will supply.*

EXAMPLE.—What amount of direct heating surface may be supplied by a steam pipe 7 inches in diameter?

SOLUTION.— $7^2 \times .7854 \times 100 = 3,848$ sq. ft. nearly. Ans.

43. Expansion Pieces.—The iron pipes that are used in steam fitting expand about $1\frac{1}{2}$ inches per hundred feet in length. In long lines of pipe this expansion must be provided for, otherwise it will make trouble by breaking connections or shoving apparatus out of place. In large pipes the expansion may be taken up by means of an ordinary expansion sliding joint.

These sliding joints are generally objectionable because of the care required to keep the packing tight and in good order. The sliding tube should be made of brass or bronze, to prevent its corroding and sticking fast.

44. Other modes of providing for the linear expansion of pipe, especially in the smaller sizes, are shown in Figs. 15 to 18. In Fig. 15 an offset is made in the pipe, and the piece *a*, which is called a **spring piece**, is made long enough to bend or spring sufficiently to permit the necessary

movement of the pipes *b*, *c* without straining the threads excessively or cracking the fittings.

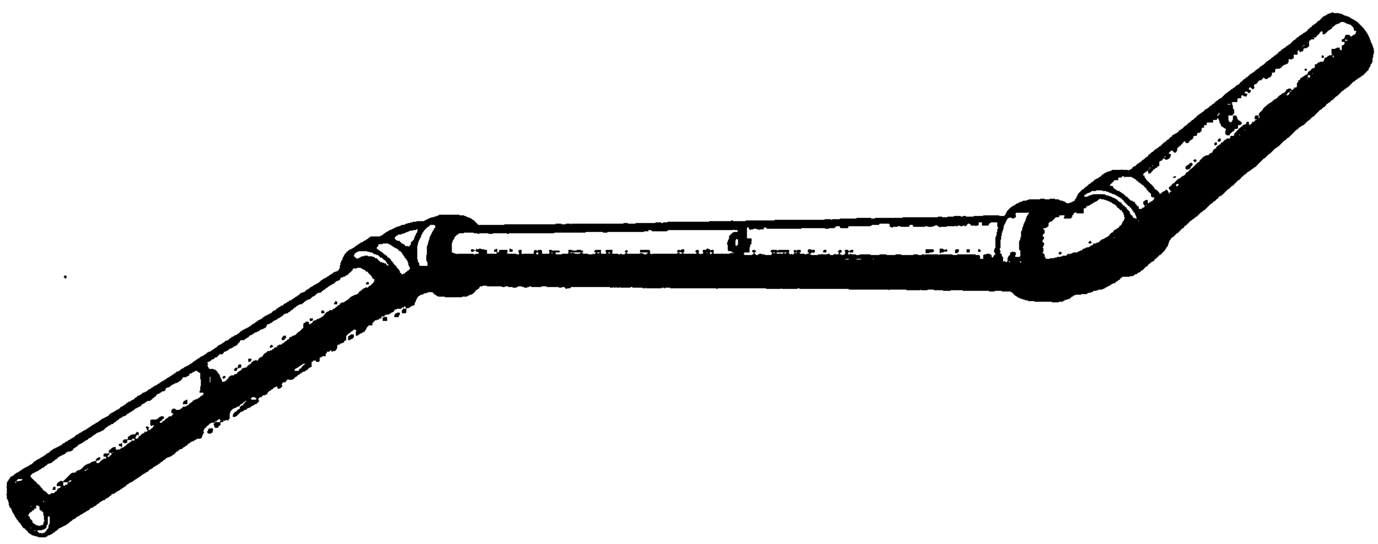


FIG. 15.

45. In Fig. 16 the spring piece *a* is bent into a **loop**, as

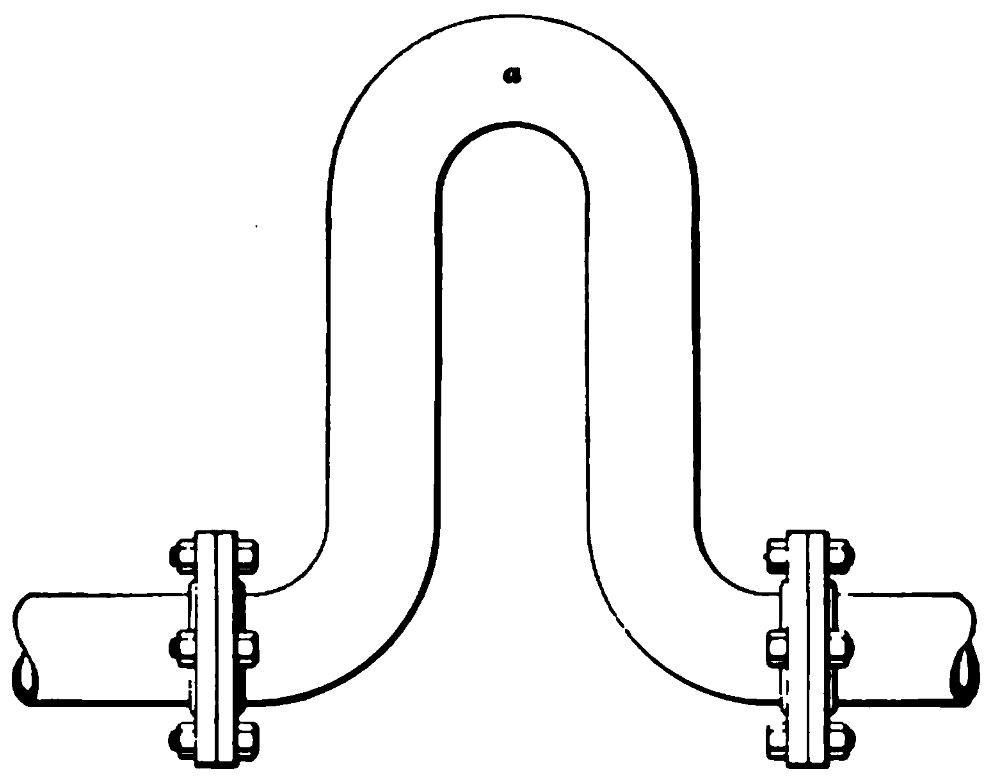


FIG. 16.

shown. Pipes of this kind are usually made of copper, with brass flanges brazed on.

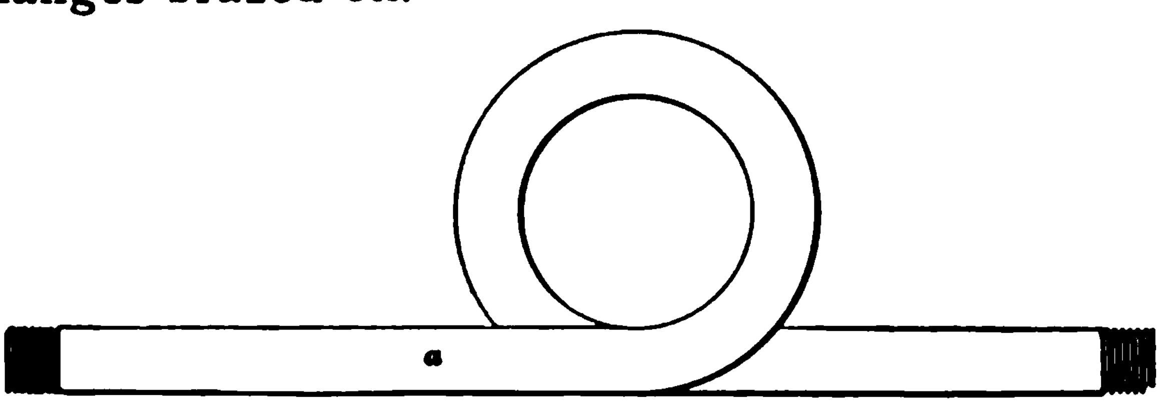


FIG. 17.

46. In Fig. 17 the pipe *a* is bent into a **coil**. This form affords such an easy bend that ordinary wrought-iron pipe

may be used without difficulty. The diameter of the circle should be large enough to spring the desired amount without serious straining.

Care must be taken in using the devices shown in Figs. 16 and 17 to avoid forming a pocket in which water or air may collect. A pocket may usually be prevented by extending the loop or coil horizontally instead of vertically

47. In Fig. 18 the connections are made so as to **swivel** instead of bend. When the pipes *b* move endwise by expan-

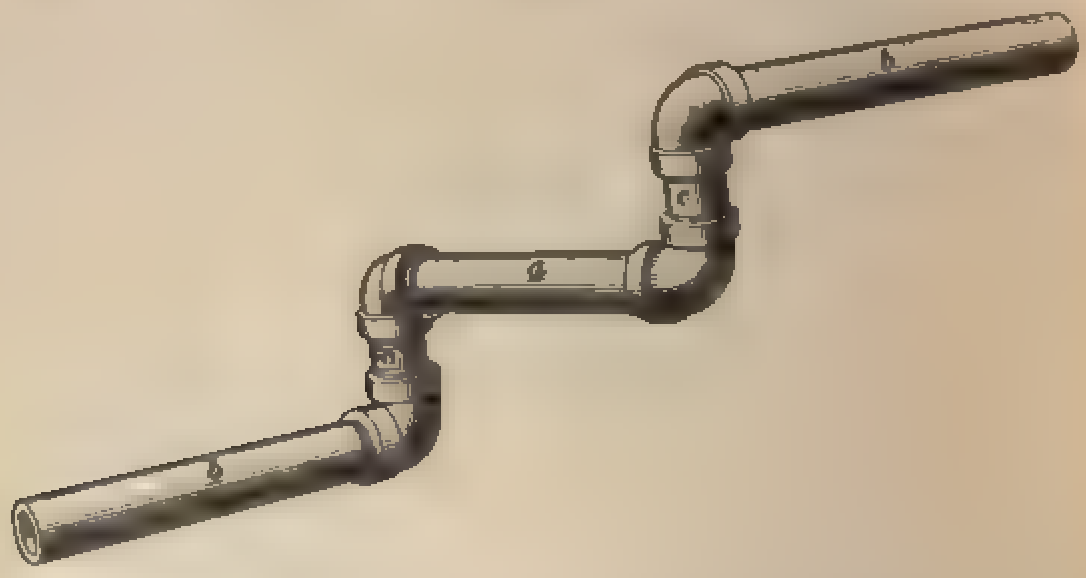


FIG. 18.

sion, the nipples *c* turn slightly in their threads and thus permit the piece *a* to swing to the requisite extent.

48. During the erection of a steam-heating plant, the matter of expansion must be carefully considered. The best point for fastening each principal pipe so that its expansion will cause the least disturbance should be determined by close examination Care must be taken to have every such pipe *free* at its ends and to see that its connections or branches are not bound or rendered immovable by plaster, brick, wood, or iron beams or columns The pipe fitter should personally inspect every such point and make sure that the pipe system is free to expand before steam is turned on.

49. Special Fittings.—Fig. 19 shows a fitting designed to make a connection between a radiator branch and a continuous riser. The partition *a* is curved so as to secure a proper supply to the radiator, and the passage *b* permits the main current to ascend without excessive obstruction. It is intended to take the place of the common fittings shown in Fig. 21 that are usually employed for the same purpose, and it also has the advantage of preserving the alinement of the parts of the riser. Fig. 20 is a variety of T Y which is designed for the same or similar use as Fig. 19.

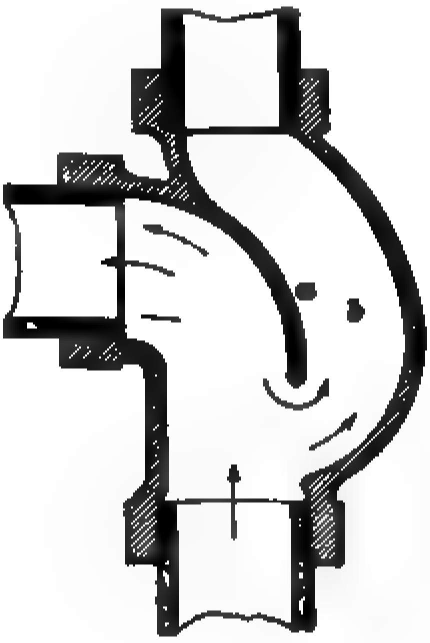


FIG. 19.

50. Fig. 22 shows an **eccentric reducer,** which serves to bring the bottoms of the connected pipes to the same level and thus prevents the lodgment of water at that point. This is particularly useful on steam mains and other nearly horizontal steam pipes.

51. Fig. 23 is a **cross,** or double T, having the branches at a higher level

FIG. 20.

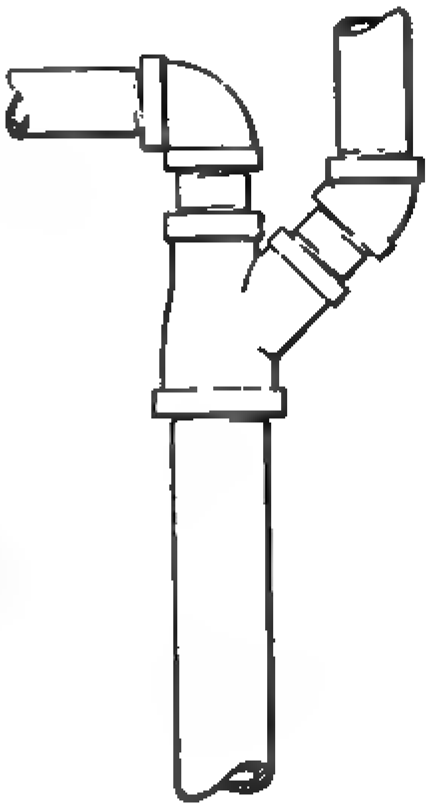


FIG. 21.

than the main pipe. This form of connection insures the proper drainage of the branches into the main steam pipe

and also prevents the water of condensation in the bottom of the main entering the branches.

FIG. 22.

FIG. 23.

PIPING A BUILDING.

52. Method of Procedure.—New buildings are piped while the work of construction proceeds, as soon as the walls are up and the roof is on. On large jobs the risers are usually put up first, next the horizontal branches are constructed, proceeding always from the riser towards the radiators, and lastly the mains are put in place. The returns are constructed at the same time and in a similar manner.

In many cases, however, particularly in small buildings, the mains are run in first, then the risers, and finally the radiator connections. This latter method avoids the use of "right and left" fittings, or unions, between the risers and the mains.

All radiator connections should be promptly capped as soon as erected, and all openings in T's and other fittings should be plugged at once, so that no dirt may get into the pipes.

53. Testing.—The piping should be tested for tightness before it is covered by plaster or flooring, so that if any defective fittings or split pipes are discovered, they may be replaced without trouble. The testing is done by filling the system full of water, every opening being tightly

closed, and then applying pressure by means of a force pump. The pressure is increased until the gauge shows from 100 to 150 pounds per square inch. Another test should be made with steam before the pipes are covered, if possible. This will determine whether the expansion is properly provided for and whether the system is in working order. The steam pressure used should not greatly exceed the proposed working pressure.

54. Clearance.—All steam pipes should be kept out of contact with woodwork or other combustible materials. A clearance of at least 2 inches should be maintained at all points, and where this cannot be had, special protection should be provided. Return pipes are liable to be full of hot steam at times, therefore they must be guarded the same as steam-supply pipes.

55. Floor and Ceiling Flanges.—Fig. 24 shows the manner of using floor and ceiling flanges to protect the

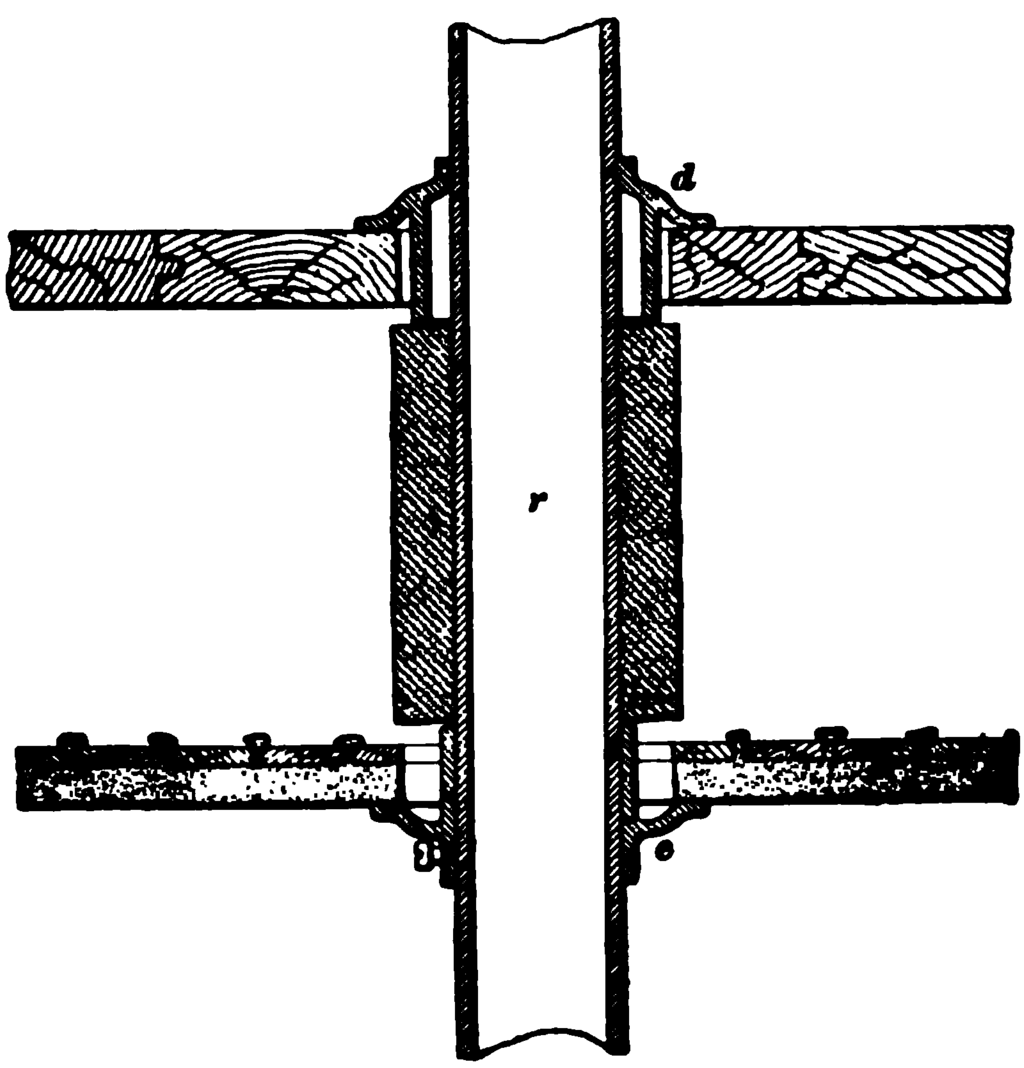


FIG. 24.

woodwork where a steam pipe passes through an ordinary floor. When the ceiling flange *e* is secured to the pipe by a

setscrew, as shown, allowance must be made in setting it for the vertical expansion of the pipe, otherwise it will be liable to break the plaster forming the ceiling when the steam is turned on; or the ceiling flanges may be secured after the steam is on. A better construction is to connect the upper and lower flanges by a nipple a size or two larger than the riser, and have a current of air flowing through the spaces between the pipes and any combustible material.

EXHAUST AND VACUUM SYSTEMS.

EXHAUST SYSTEM.

56. Saving Effected.—The **exhaust system** is in every respect a low-pressure system, except that it is provided with special apparatus that adapts it to receive the exhaust steam from engines and pumps. It is used only for the purpose of utilizing and saving the heat in exhaust steam that would otherwise go to waste.

The magnitude of this waste may be easily seen when it is considered that exhaust steam at 5 pounds gauge pressure contains 971 British thermal units per pound that are available for heating, and if not thus used, would be discharged through the exhaust pipe into the atmosphere.

The practice of allowing exhaust steam to escape into the atmosphere in any situation where it can be used in heating apparatus, either for housewarming or heating liquids, etc., is, therefore, inexcusably wasteful.

57. General Arrangement.—The general arrangement of apparatus for controlling the steam supply and drainage in an exhaust system is shown in Fig. 25. The steam-heating main *a* is connected to the exhaust pipe *b* and also to a pipe *c* that supplies live steam from the boilers. This steam passes through a pressure-reducing valve *e* and is lowered in pressure to the desired amount before entering the heating main. By this arrangement the heating system will be supplied with exhaust steam as long as the engines

are in operation, but if for any reason the supply becomes insufficient to maintain the proper pressure, then live steam will enter through the reducing valve and make up the deficiency. If the supply of exhaust steam becomes excessive, so that the pressure rises unduly, the excess will escape by opening the back-pressure valve *f* and blowing into the

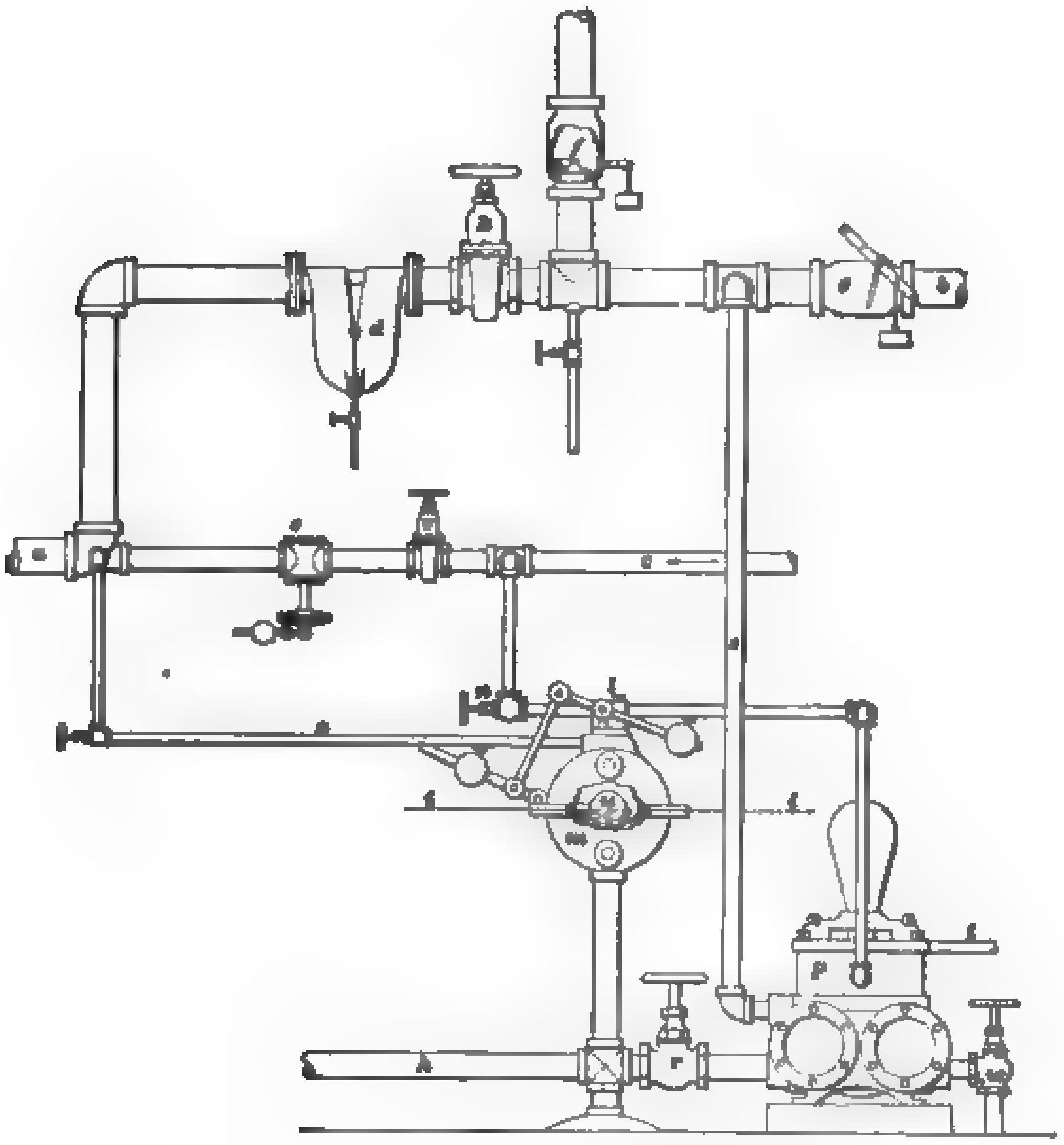


FIG. 25.

atmosphere. When the engines are stopped, the steam in the heating apparatus is prevented from passing backwards and filling them with water by means of the check-valve *g*. This valve is similar to the valve *f* in construction and is so nearly balanced by its counterweight that it will open very easily. The relief valve *f* is usually adjusted to

blow off at a pressure about 1 pound higher than that maintained by the reducing valve *c*.

The exhaust steam is passed through a separator *d* before entering the heating system, for the purpose of removing the entrained water, and especially for removing the oil that accompanies it from the engine.

58. Disposal of Drainage.—The drainage from the heating apparatus is collected in the pipe *h* and is returned to the boiler by means of a pump *p*, as shown. The returns have no direct connection with the boiler, consequently the water level in them may be maintained at any convenient height, as at *i i*. This is accomplished by means of the pump and its governor *m*. The **pump governor** is merely a closed vessel containing a float *n* that rises and falls with the water level. The steam that drives the pump is taken from the high-pressure pipe *c* through the stop-valve *u* and passes through a throttle valve *l* that is controlled by the float. When the water rises above the desired level, the float opens the throttle and starts the pump; when it subsides, the float is lowered and shuts off the steam. The exhaust from the pump is turned into the exhaust main through the pipe *s*. The pump governor is connected to the heating main *a* by a small pipe *o* for the purpose of equalizing the pressure on top of the water therein.

59. Location of Valves. Valves are provided in the main pipes, at *k* and *z*, for the purpose of shutting off the heating apparatus during the summer season. It will be noted that these valves are located so that they do not interfere with the supply of steam to the pump nor with the exhaust therefrom. The returns are shut from the pump by the valve *r*, and an independent water supply is attached at *w*. The pump delivers through the pipe *t* to the boiler.

60. Care must be taken to locate the valves *f* and *g* in proper relation to each other, as shown. If the check-valve is placed between the heating main *a* and the valve *f* and the reducing valve *e* should get out of order, the pressure

would rise in the heating system until it equalled that in the boiler. This would probably burst the radiators and do serious damage. The safety of the whole apparatus depends on the good working condition of the relief valve *f*.

VACUUM SYSTEM.

61. General Description.—The **vacuum system** of steam heating differs from all others in one important particular, which is, that a vacuum, more or less perfect, is constantly maintained in the returns. This permits the system to be operated with steam of any convenient pressure, high or low, and from any source, either exhaust or otherwise. The pressure and temperature throughout the whole system may be adjusted and maintained at any degree between full-boiler pressure and a low vacuum, thus making the system adjustable to suit all conditions of weather and service.

Generally the system is operated with exhaust steam, the supply being arranged as shown in Fig. 25. The piping is usually arranged on the two-pipe system, and the returns are generally made independent, although it is not necessary to do so in all cases.

62. Essential Features.—Fig. 26 shows the essential features of the system. The returns *a*, *a* are connected to a receiver *b*, which collects all the air and water in the system. These are pumped out by means of the **vacuum pump** *v*, which thus maintains a constant vacuum of any degree desired in the returns.

By this arrangement any steam may be used in the radiators that is warm enough to operate the traps or "thermostatic valves" that are placed on the return end of each radiator to open automatically when water or air is required to pass through, but to close when steam begins to pass through. This prevents the returns from becoming filled with steam. The vacuum system permits steam to be used at a pressure far below that of the atmosphere and at any temperature down to about 140°, the limit being fixed only

by the ability of the pump to keep up the vacuum in the returns.

63. There are various forms of exhausting apparatus that may be used in place of the pump, to maintain the vacuum, such as "injector condensers," etc., but as they are not an essential part of this system, they will not be described here.

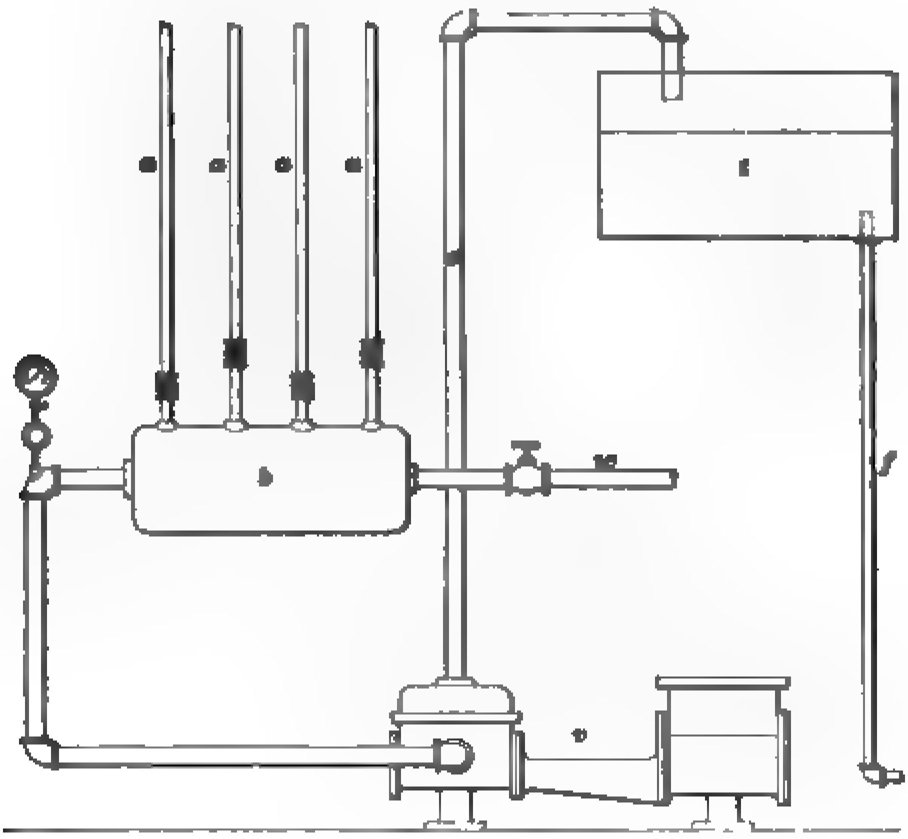


FIG. 26.

The water and air that are drawn from the receiver by the vacuum pump are discharged into an open tank, from which the air readily escapes. The water is then pumped back into the boiler by any ordinary feed-pump.

64. In some cases, the fresh, cold water, which is otherwise required to feed the boilers, is injected into the receiver in a series of fine streams through the pipe *w*, the object being to condense as much as possible of the steam that may be present and thus improve the vacuum. At the same time that the water becomes warmed it gives up the air accompanying it, thus increasing the amount to be removed by the pump. This air expands into the vacuum and partially neutralizes the effect of the condensation. Thus it will be

seen that the introduction of the feedwater into the system at this point is of doubtful utility. If it is sent through an ordinary feedwater heater instead, it will become much hotter and the air will be eliminated without difficulty.

65. Advantages.—It will be understood that when the exhaust steam from an engine is turned into the ordinary low-pressure heating system, the back pressure is increased, and the efficiency of the engine is correspondingly decreased, sometimes to such an extent as to become very detrimental.

One of the principal advantages of the vacuum system is that a great part of the back pressure is taken off the engines, and the capacity of the engines to do useful work is thereby increased.

The size of the piping required for the vacuum system of steam heating is about the same as for the ordinary low-pressure system. The volume of the steam required is greater, owing to the low pressure, and the amount of heat per cubic foot is correspondingly less than that found in ordinary heating systems, but the difference between the pressures of the steam in the supply pipes and in the returns is so great that the volume of steam necessary to carry the amount of heat required is driven through the pipes without difficulty.

The radiators, however, must be larger than for any other system, in proportion as the temperature of the steam used is lower.

DISTRICT SYSTEM.

66. The **district system** of steam heating is practiced in large towns and cities by means of steam mains that are laid underground through the streets. The arrangement of the connections from the street mains to the house pipes is shown in Fig. 27. The service pipe *a* is provided with a valve *b* inside the basement wall, so that the house system can be shut off when desired. The steam passes through a pressure-reducing valve *c* and thence into the distributing pipe or house main *e*. The water that may enter from the service pipe is led away by the drain pipe *d*. The returns

are all connected into the pipe *f*, which is submerged below the water level. The level of the water in the returns is fixed by the elevation given the steam trap *t*; thus, in the figure, it is at the line *g*. The hot water from the trap should never be discharged directly into the house drains, because of its destructive effect upon the pipes, but should be cooled before escaping to the sewers, by first allowing it to flow through a coil of pipes. This coil is usually called a

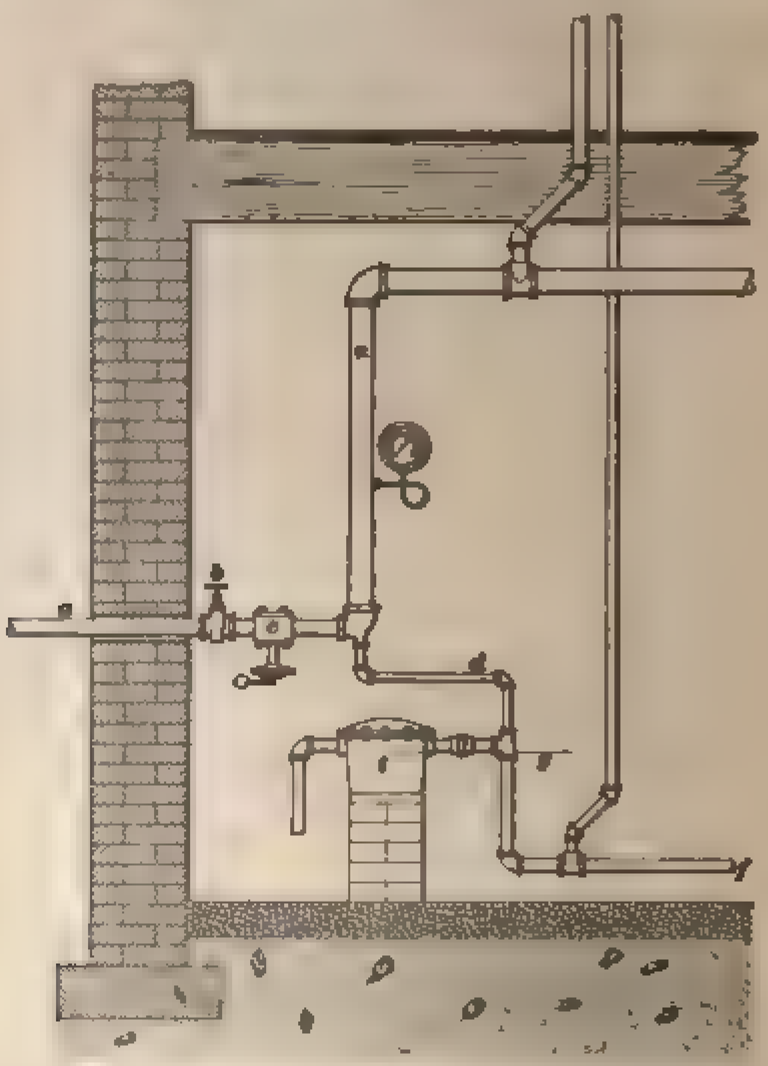


FIG. 27

"cooling coil." It should never deliver directly into the drainage system, but in all cases should deliver into a deep, sealed trap. This is to prevent drain air entering the heating system or the building. The trap, or hotwell, should always deliver into the house-sewer connection on the sewer side of the main drain trap, to prevent hot vapors passing up the iron drainage system in the building.

HEATING SYSTEM DETAILS.

AIR VENTS AND TRAPS.

67. Air Vents.—All automatic air vents on steam-heating systems are *thermostatic* in principle, that is, they are controlled by a difference in temperature between the steam and the air that is to be expelled from the heating apparatus.

Fig. 28 shows the construction of an ordinary air vent. The shank *a* is screwed into a radiator tube and the nozzle *d* is connected to a suitable drip pipe. The valve *c* is a rod composed of some expansible material that is adjusted against the steam orifice by means of the screw *b*. When air enters the orifice *e* instead of steam, the rod *c* cools and shortens slightly, thus opening the orifice and permitting the air to flow through. As soon as hot steam arrives, however, the rod expands and again closes the vent.

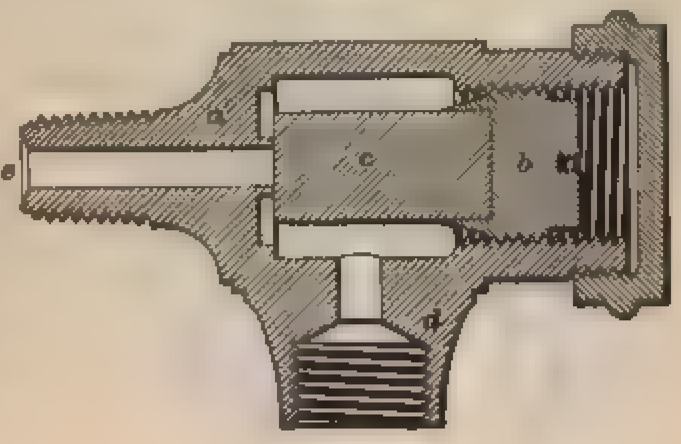


FIG. 28.

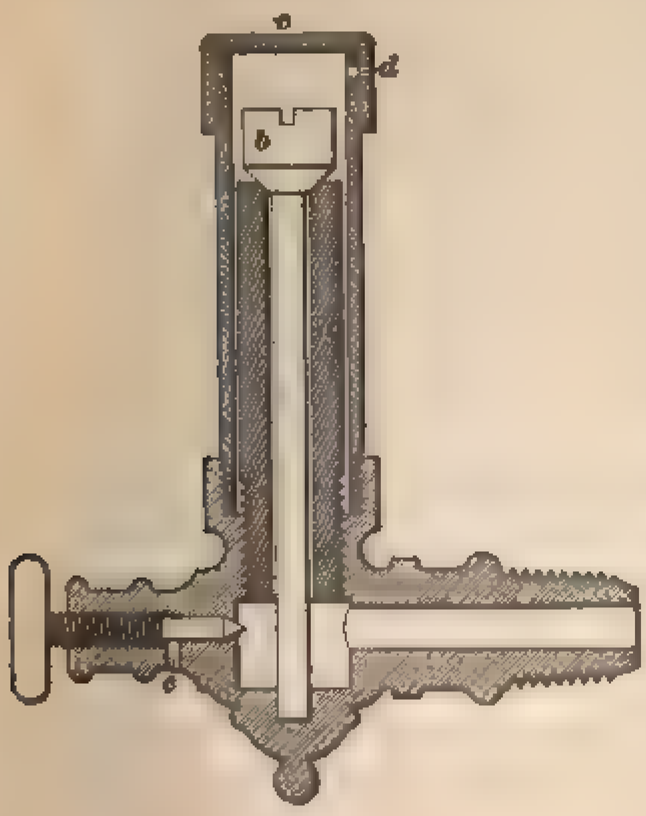


FIG. 29

68. The length of the expansible element that is exposed to the air or steam is very small, consequently the opening of the vent will be very slight and quite slow in operation. This is improved in the construction shown in

Fig. 29. The expansible rod *a* is much longer and is hollow. Its whole interior surface is exposed to the steam or air at all times. The lower end is screwed fast to the body of the vent and the upper end draws away from the valve *b* when contraction occurs from the cooling influence of air. The valve *b* has a long stem that screws into the bottom of the chamber, and it is easily adjusted by means of a screw-driver when the cap *c* is removed. The air passes through the vent hole *d*. A small screw valve *e* is added for relief by hand when desired.

Both of the devices shown will permit the escape of water as readily as air, therefore they should be provided with suitable drip pipes. Otherwise, they are very liable to discharge water at almost any time and thus make serious trouble.

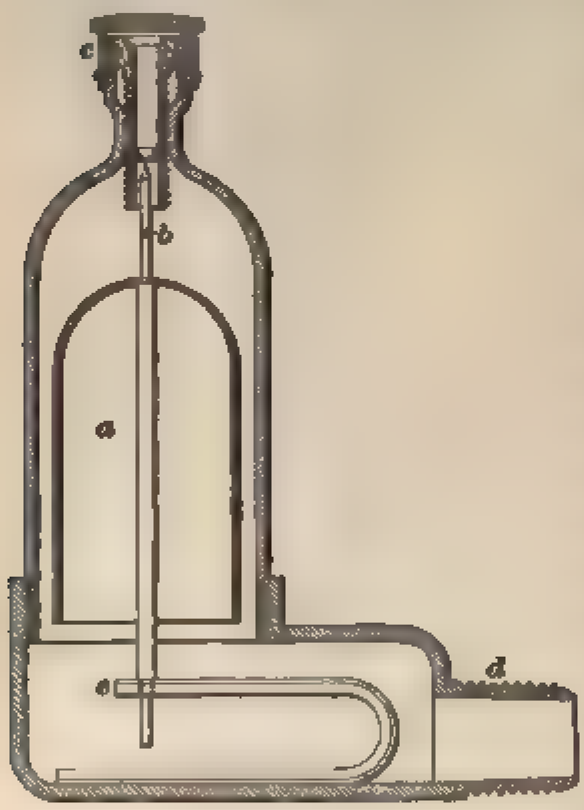


FIG. 30.

69. In Fig. 30 the trouble mentioned in Art. **68** is remedied by attaching a cup or float *a* to the stem of the air valve *b*. This stem rests loosely on the bent spring *c*, and when the chamber fills with water, the float will lift the valve and close the vent. The valve is opened to discharge air by the bending of the spring, which is made of two strips of different metals firmly soldered together. These contract by different amounts when cooled, thus bending the spring and allowing the valve to open slightly.

70. The proper place to attach an air vent to a radiator or coil is at a point as far as practicable from the steam inlet, so as to prevent the current that moves towards the

vent carrying hot steam to it and thus closing it before all the air has escaped

71. Return Traps.—Return traps are used only for returning the water of condensation to the boiler. It is immaterial whether the pressure in the boiler greatly exceeds that in the heating apparatus or not; they are equally serviceable for all cases. They require to be set above the water level in the boiler, at a sufficient elevation to allow the water to flow from them into the boiler by gravity.

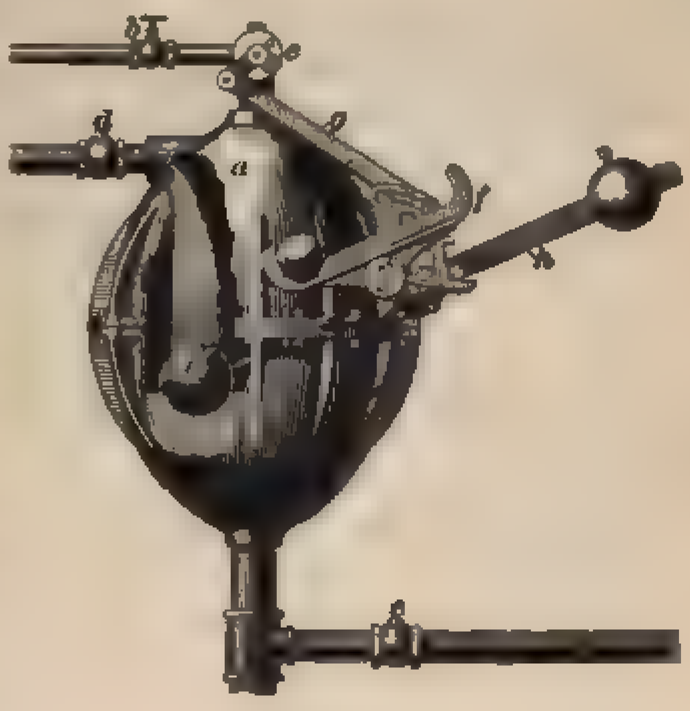


FIG 31

72. Fig. 31 shows a very common form of a return trap. It is composed of a globe *a* that performs the duty of a condenser and receiver, and the connecting pipes on which are attached the valve *b* and check-valves *c* and *d*. The pipe on which *c* is placed joins the boiler, usually below the water-line, and the pipe on which *d* is placed joins a receiver that is set at the lowest ends of the return mains to receive water of condensation from the heating system.

The pipe on which *b* is placed joins the steam space of the boiler. A rotary slide valve *e* engages with a rocking casting *f* by means of a connecting link *g*, the engaging point between *f* and *g* being provided with slack motion, as shown.

A lever *h* having a float *i* on one end (inside the trap) and a counterpoise weight on the other end also engages with the casting *f* by a slack-motion connection, as shown.

A track is formed in the casting *f* along which the solid ball shown may roll.

73. The action of the trap is as follows. When a vacuum has been formed in the globe *a* by the condensation of steam, water of condensation from the receiver will flow through *d* and into the trap, as shown, and will continue flowing until the trap is full or the receiver empty, providing the trap is not set too high. As the water rises in the trap, the float *i* will rise with it and the loaded end of the lever *h* will descend correspondingly. As this movement of *h* continues, the stud that engages *h* with the casting *f* pushes down that end of *f*, thereby bringing the track nearer a level position. This it does without moving the rotary valve *e* on the steam connection, because of the slack motion between *g* and *f*.

As soon as the end of the track on which the ball rests is raised above the level of the other end, the ball will roll along the track, strike the opposite hooked end, and cause it to fall rapidly, opening the steam valve *e* to its full extent. At this point, the trap is about full of water, and since the full boiler pressure is now placed on the surface of the water in *a* and since this water is higher than that in the boiler, it will be easily seen that the water in *a* will simply fall by gravity into the boiler.

As the water drains from *a*, the float *i* will descend, and when it has reached the bottom of the globe, the track will be tilted in the opposite direction by the ball, when the steam valve *e* will be suddenly closed and the trap will be prepared to receive another charge from the heating system as the steam condenses in the globe.

74. The height to which water can be lifted is limited by the difference between the pressure in the receiver and the vacuum formed in the trap. As nearly all varieties of return traps depend on the formation of a vacuum in order to become filled with water, it is essential that air be carefully excluded from them.

RADIATORS AND COILS.

75. Form of Heating Surfaces.—Heating surfaces, i. e., the exterior surfaces of radiators and coils, that have no projections of any kind are classified as **plain surfaces,** while those having ribs, knobs, pins, or other projecting parts are called **extended surfaces.**

The object sought in the construction of extended surfaces is to make the area of the emitting surface greater than that of the absorbing surface. By this means heat may be transferred from a fluid that gives it off readily to one that takes it up slowly with but little decrease in temperature of the heat-transmitting surfaces.

A plate having extended surfaces will emit more heat per hour than the same plate without the extensions, but less than a plain plate having the same actual area of exposed surface.

Extended surfaces have no advantage over plain surfaces unless the velocity of the air passing over them is sufficient to sweep them clean of hot air as rapidly as it is formed. When air is moved wholly by convection, as is the case when a radiator stands in still air, the plain surfaces clear themselves of hot air better than do the extended surfaces and are, therefore, more effective.

76. Efficiency of Radiators.—The efficiency of a heater or radiator will increase as the velocity of air passing over it is increased, but not in the same proportion. With increased velocity, the duration of contact of air with the hot surface is shortened and the rise of temperature will be less, but the quantity of air heated will be increased so much that the total heat given off from the radiator per square foot of surface per hour will be increased.

77. Arrangement of Heating Surfaces.—The efficiency of a radiator will depend, to a considerable extent, on the direction in which the air is moved over the heating surfaces. Fig. 32 shows a vertical tube standing in still air. The tube is heated by steam and its surface has a

temperature that is practically uniform throughout. The air, which is warmed at the lower end of the tube, flows upwards and envelops the upper part in a current of hot air. The emission of heat will be slower from the upper part of the tube than from the lower part, because the difference in temperature between the air and metal is less.

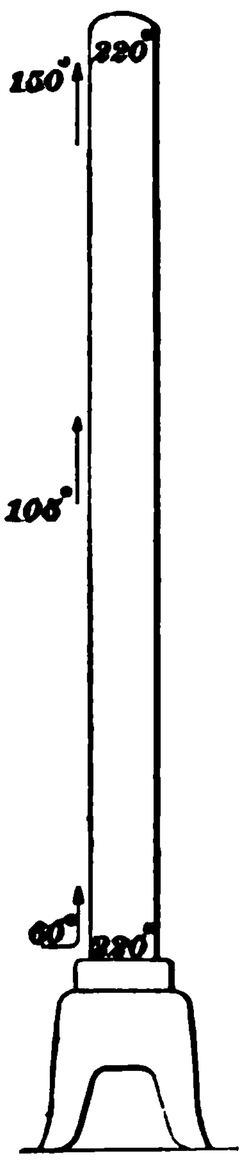


Fig. 32.

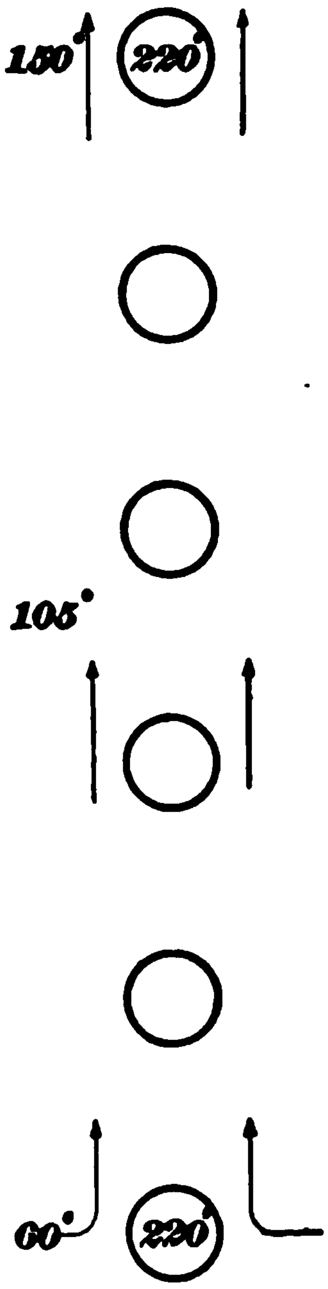


Fig. 33.

The temperature at the various points is marked on the sketch.

A similar loss of efficiency occurs in a common coil of horizontal pipes laid vertically over one another, as shown in Fig. 33. The upper pipes are enveloped in the warm air that has been heated by the lower pipes.

78. The maximum efficiency can be attained by placing the coil or radiator in a horizontal position, as indicated in Fig. 34. Each tube will then operate upon air of equally low temperature, and, consequently, the rate of emission will be

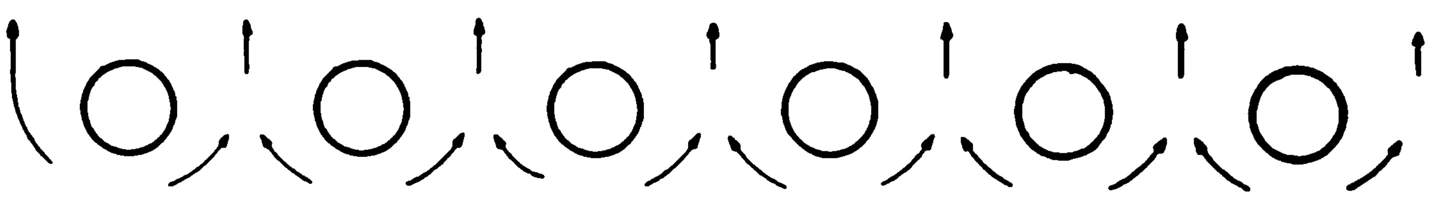


Fig. 34.

greater than in the cases shown in Figs. 32 and 33.

79. If radiator tubes are grouped together in large numbers, as in Fig. 35, the efficiency of the tubes in the interior of the group will be much less than that of the outside tubes, because the access of cold air to them is practically cut off, and they can act only on air that has already been warmed by the outer tubes.

Their efficiency is still further reduced by the fact that nearly all the heat that they emit by radiation is intercepted and cut off by the outer tubes.

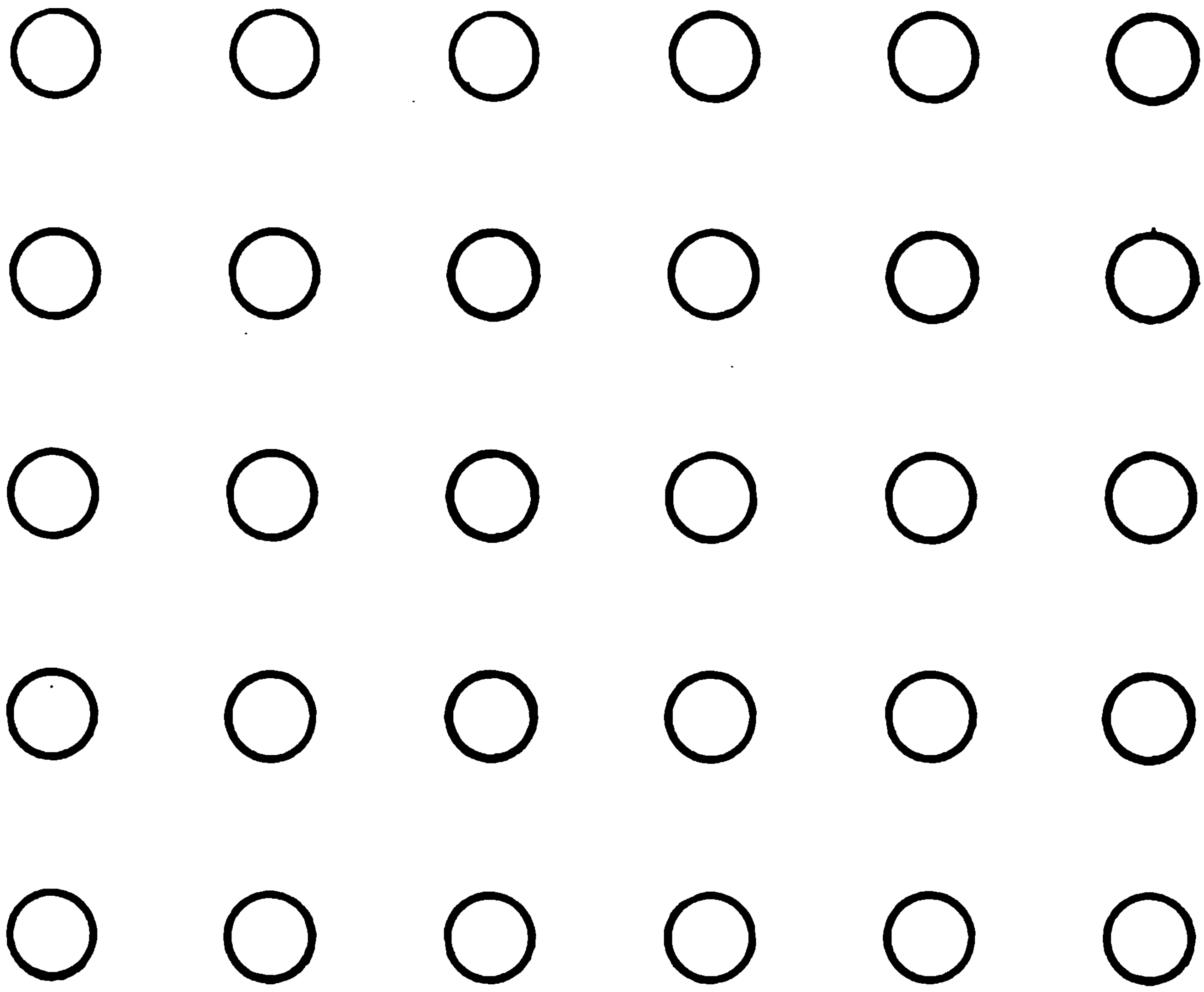


FIG. 35.

Therefore, the most effective form of radiator or coil for direct heating is one having only a single row of tubes.

80. Flue Radiators.—Figs. 36 and 37 show varieties of radiator tubes that are so shaped that, when they are assembled in a group, they enclose vertical air flues as shown at *a*. The bases of the tubes are set high enough above the floor to permit an abundant flow of air into the flues at the bottom. Radiators constructed in this manner are called **flue radiators.**

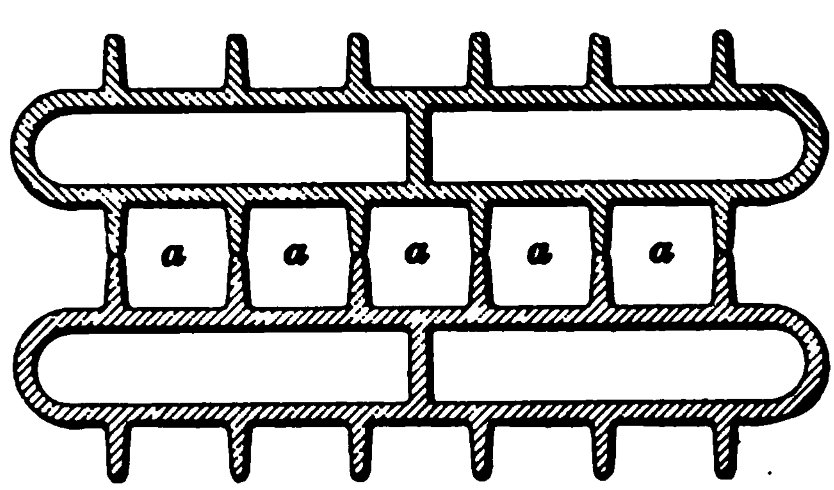


FIG. 36.

The advantages of this construction are that the interior parts of the radiator are fairly well supplied with air and that the flues impart a higher velocity to the air than it would otherwise obtain. The emissive capacity of the two forms shown in Figs. 36 and 37 will differ greatly with the relative amount of plain and extended heating surfaces that they afford, and also with the proportion of heating surface to the area of the flues.

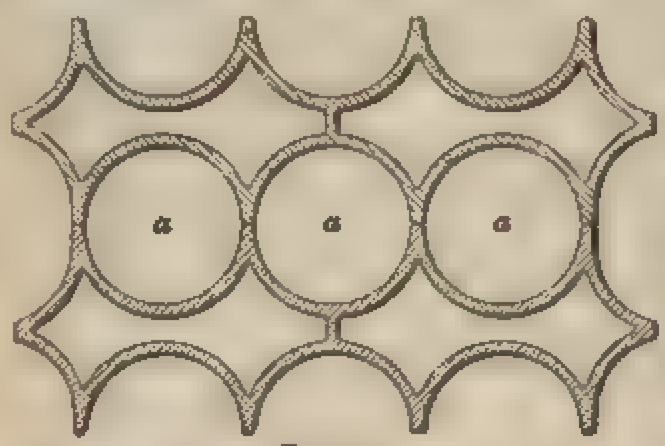


FIG. 37.

81. Continuous Flat Coil.—The continuous flat coil, Fig. 38, is made of straight pipe connected by return bends.

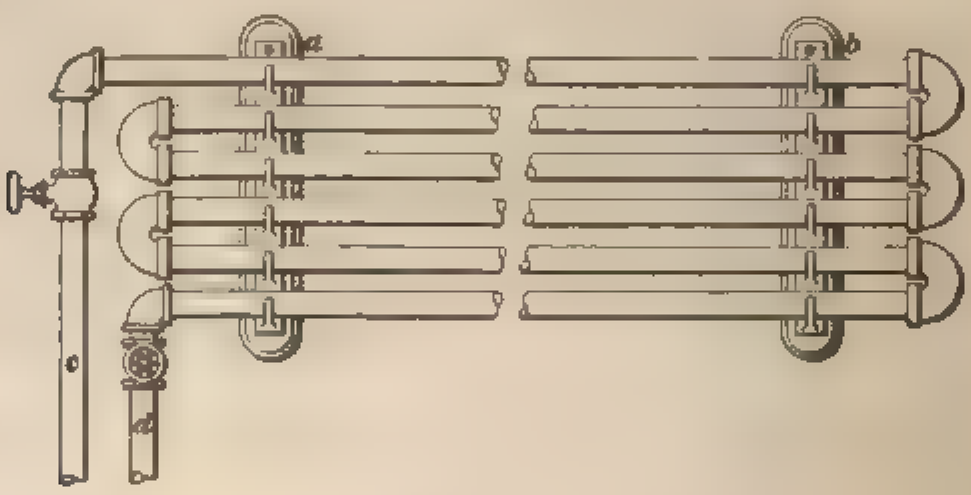


FIG. 38.

The circulation of the fluid through it is direct and certain, and it is regarded as the most efficient form of radiator in common use.

82. Miter Coil.—A miter coil is shown in Fig. 39, the pipes being connected between two manifolds *a* and *b*. The steam moves forwards simultaneously through all the pipes; therefore, its velocity will be one sixth the rate in a single

pipe, as in Fig. 38. The circulation is likely to be uneven, because the fluid entering at *g* will naturally, owing to its momentum, flow to the end of the manifold, and so a greater quantity will enter the pipe *e* than pipe *f*. The path through *e c* is shorter than through *f d*, and, the friction being less, the main part of the current will go that way.

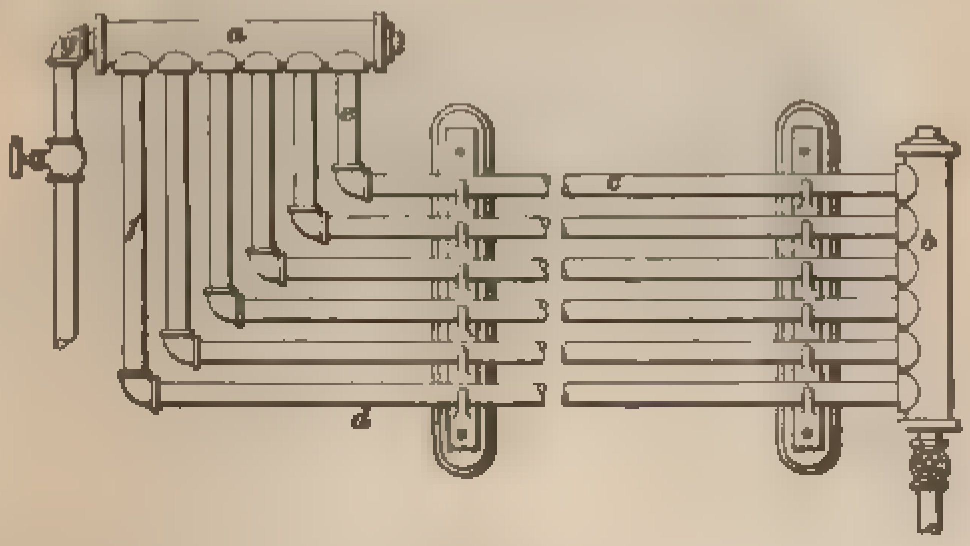


FIG. 39

It will be noted that all the horizontal pipes are connected to the manifold *a* by means of elbows and vertical pipes. This must always be done, so as to permit the several pipes to expand independently, as their varying temperatures may require. The vertical pipes will bend or yield sufficiently to accommodate the difference in expansion.

FIG. 40

83. Manifold Coil. If a coil is made by connecting two manifolds, as in Fig. 40, it will be difficult to keep it steam-tight. The upper pipes will expand more than the lower

ones, and they will either bulge and spring, as shown, or they will crack or break some of the connections

84. Box Coil.—When several flat coils are grouped together, as shown in Fig 41, the construction is called a **box coil.**

FIG. 41

The spring pieces of a coil should be put together with right-and-left screw joints, so that the coil may be readily disconnected at any time and without unnecessary labor.

85. Size of Pipe for Coils.—The size of pipe used for constructing coils depends chiefly on the pressure of steam to be used, the length of the coil, and the force of the circulation through it. A coil like Fig. 39 could be made of smaller pipe than one like Fig 38, because the current of heating fluid is diffused throughout the whole series instead of passing entirely through each pipe. The difference, however, would seldom exceed one or two sizes of pipe. The customary size of pipe used is from 1 inch to 1½ inches—the latter being used for exhaust-steam heating.

Pipe coils must be arranged so that all water that is condensed within them may flow easily towards their outlets.

86. Nason Tube.—Fig. 42 shows a tube called the **Nason tube.** It is connected to the radiator base by a single screw joint and is divided into two passages by means of a sheet-iron plate *a* that extends nearly to the

top of the tube, as shown. The steam rises on one side, passes over the end of the plate, and descends on the opposite side of the tube. Each tube thus forms a complete *loop*, or circuit.

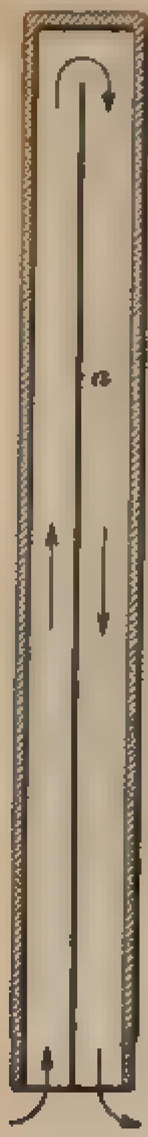


FIG. 42.

FIG. 43.

87. Bundy Loop.—Fig 43 shows the Bundy loop, in longitudinal section at *A* and cross-section at *B*. This, also, is screwed into a cast-iron radiator base of suitable shape, and the steam moves up one branch of the tube and down the other.

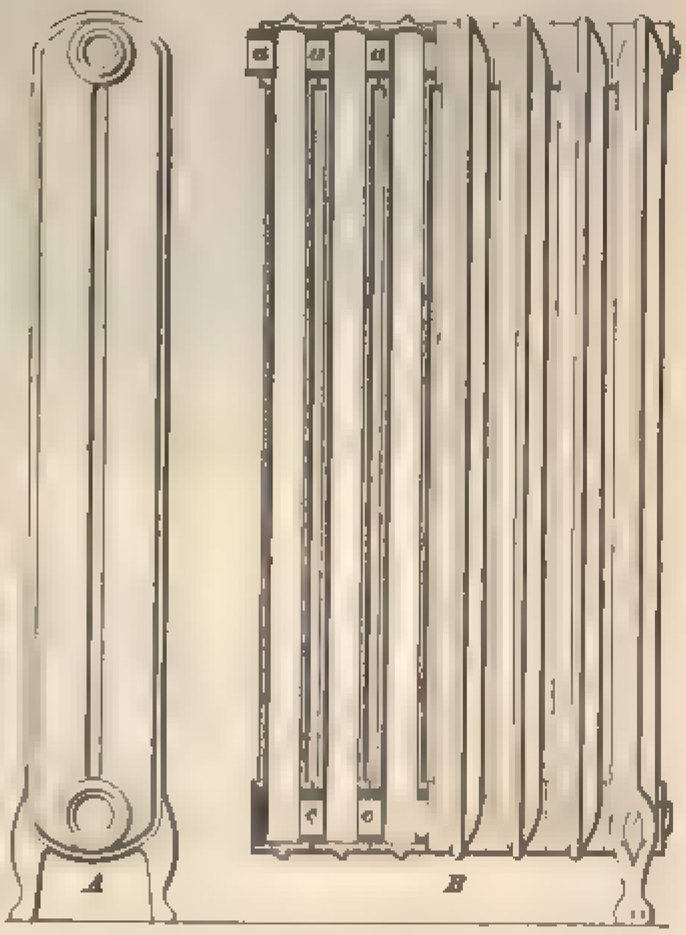


FIG. 44

88. Detroit Loop. The Detroit loop is shown in Fig 44 Each loop is complete in itself and requires no base or supply chamber. The loops are connected together, in any number desired, by means of nipples *a* and *c*. When the connection at the top is not desired, the loops are bound

together by a bolt that passes through the space between them, shown in the end view.

The construction of this class of loops is often varied so that they comprise three or even four parallel tubes. They are also modified so as to form flue radiators.

89. Pin Radiator. Fig. 45 shows an extended surface indirect radiator that is in extensive use for indirect heating.

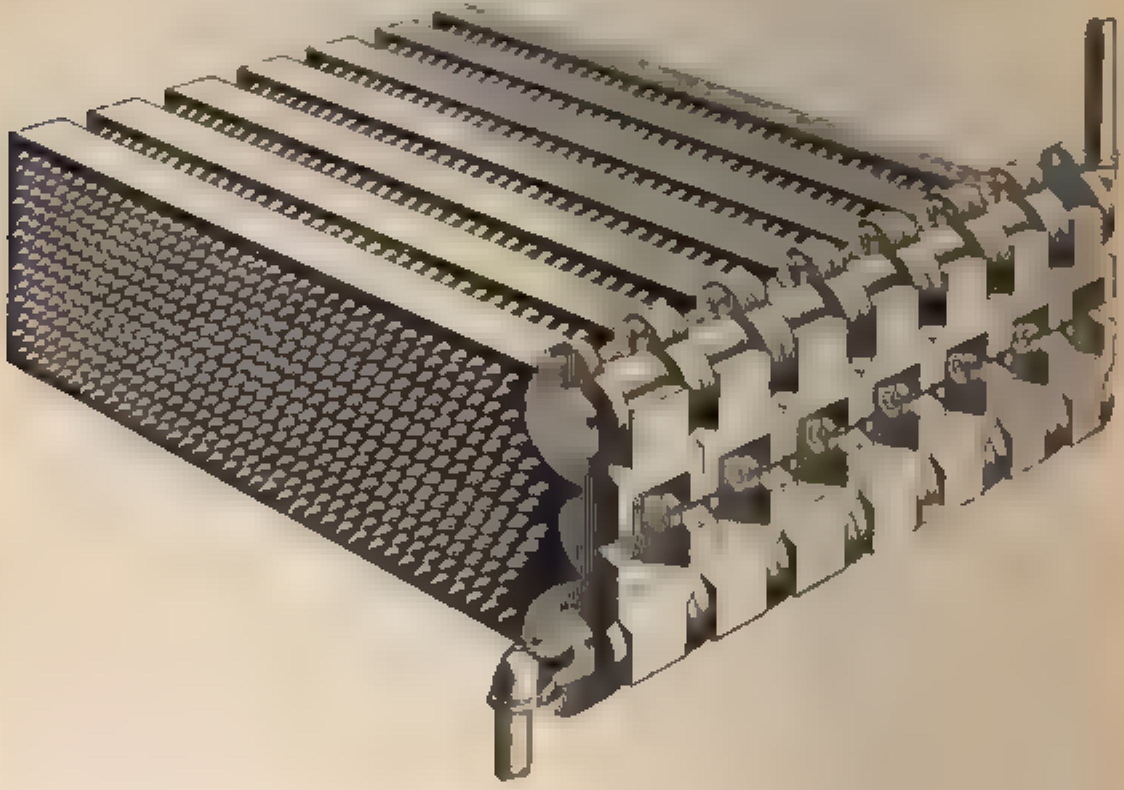


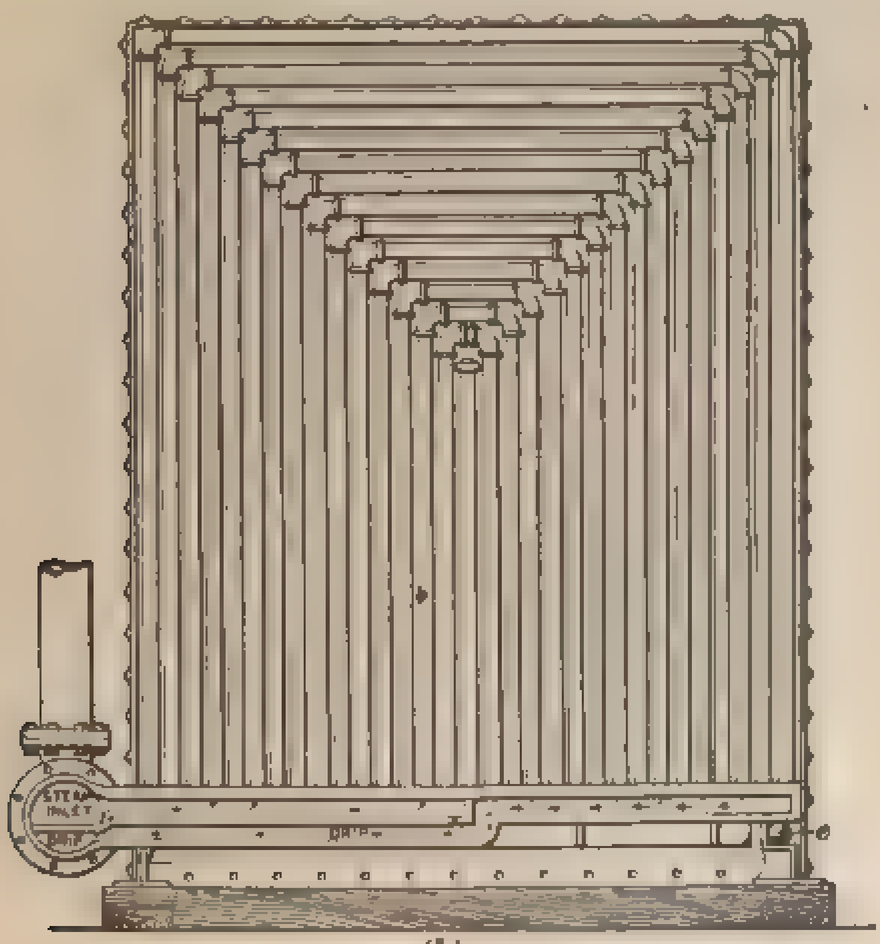
FIG. 45.

It is called a **pin radiator** because the extensions of the heating surface are made in the shape of small conical pins. The air flows up between the sections and impinges against the pins.

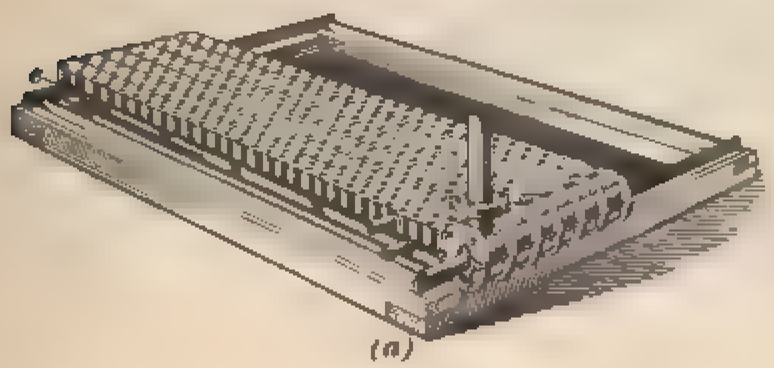
90.* **Forced-draft heaters,** which are commonly used for heating air on a large scale, where forced draft is used, are constructed in a manner similar to that shown in Fig. 46; (*b*) is an elevation and (*a*) a plan. The tubes are of 1-inch steel or wrought-iron pipe and are connected at the top by

cross pipes instead of return bends, thus preventing all distortion by unequal expansion.

The tubes are *staggered*, so that those in one row stand opposite the spaces between the tubes in the preceding row.



(b)



(a)

FIG. 46.

By this means, all parts of the air-current (which passes through horizontally) are brought into contact with the tubes and thoroughly heated.

The *base sections*, or *headers*, are coupled together at one end by flanged joints. The group of base sections may be divided into two or more parts, each of which may have an independent supply and return pipe. Thus, the whole heater may be used or only a part of it, as desired. The sides of the sections are corrugated so that they interlock and leave no open spaces between them. The farther end of each section rests upon a roller *c*, so that they can expand and contract freely without straining. The course of the steam through the heater is shown by the arrows.

91. The ordinary varieties of vertical-tube radiators may easily be adapted to direct-indirect heating. The mode of applying a direct radiator of the Nason or Bundy type to that purpose is shown in Fig. 47. The base of the radiator is enclosed by plates *a*, so that the fresh air, which comes in through the tube *b*, is compelled to pass upwards and between the hot tubes before it can escape into the room.

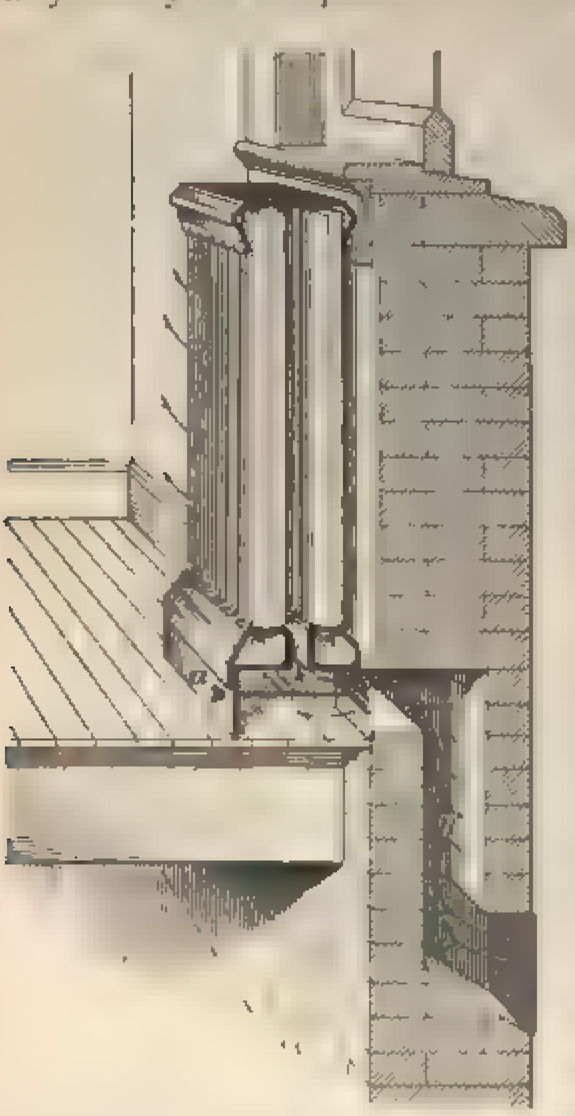


FIG. 47

92. Proportioning Radiation Surface.—To correctly determine the amount of radiation required to properly warm a given space requires the best judgment of a heating engineer. A number of rules and formulas for determining radiation are in use; some are simple and some are complicated. The following table gives the allowance of heating surface commonly supplied for ordinary purposes:

TABLE IV.

TABLE FOR PROPORTIONING RADIATION SURFACE TO CUBICAL CONTENTS OF ROOM TO BE WARMED.

Space to be Heated.	Allowance of
Bathrooms and living rooms with three exposed walls and a large amount of glass surface....................................	1 square foot for each 40 cubic feet.
Bathrooms and living rooms with two exposed walls and large amount of glass surface....................................	1 square foot for each 50 cubic feet.
Bathrooms and living rooms with one exposed wall and ordinary amount of glass surface....................................	1 square foot for each 60 cubic feet.
Sleeping rooms............	1 square foot for each 60 to 70 cubic feet.
Halls....................................	1 square foot for each 50 to 70 cubic feet.
School rooms.............................	1 square foot for each 60 to 80 cubic feet.
Churches and auditoriums having large cubical contents and high ceilings........	1 square foot for each 65 to 100 cubic feet.
Lofts, workshops, and factories.............	1 square foot for each 75 to 150 cubic feet.

The foregoing simple table applies to direct radiation only. If indirect radiators are used, allow not less than 50 per cent. more surface. If direct-indirect radiators are used, allow not less than 25 per cent. more surface. In estimating radiation, make ample allowance for exposure of building, materials of construction, and loose doors and windows.

93. We do not recommend the general use of any method of proportioning radiation to the cubical contents of the rooms to be heated. The foregoing is presented for the convenience of those who may be able to use it with good judgment and for "checking up" purposes.

94. One of the most simple and probably most correct empiric rules used for computing the size of direct radiators is that originated by Mr. William J. Baldwin, a well-known American heating engineer, and is as follows:

Rule 3.—"*Divide the difference between the temperature at which the room is to be kept and that of the coldest outside atmosphere by the difference between the temperature of the steam pipes and that at which you wish to keep the room, and the quotient will be the square feet, or fraction thereof, of plate or pipe surface to each square foot of glass, or its equivalent in wall surface.*"

The quantity of heating surface found by this simple rule merely compensates for the amount of heat lost by transmission through the windows, walls, and other cooling surfaces; it does not provide for cold air entering the room through loosely fitting doors, windows, etc., and an ample allowance must be made for this. Some buildings are so poorly constructed that 50 per cent. or more must be added to the amount of heating surface obtained by the above rule, in order to counteract the cooling effect of these air leakages. A common practice is to add 25 per cent. for buildings of ordinarily good construction. Besides this addition for air leakage, an ample allowance should be made for rooms exposed to cold winds, and this allowance should, if possible, be made in the form of an auxiliary radiator to prevent overheating the rooms during moderate weather.

95. Suppose that we have three rooms *A*, *B*, and *C*, as shown in Fig. 48, of precisely the same dimensions, and, consequently, having the same cubical contents, the rooms being each 25 feet long by 20 feet wide, with a 10-foot ceiling.

Let us also suppose that the halls, or corridors, *D* and the other rooms in the building will be warmed to a temperature equal to that desired in *A*, *B*, and *C* by other radiators not shown. First proceed to find, by rule **3**, Art. **94**, the amount of heating surface required to maintain a temperature of 70° F. in *A*, *B*, and *C*, assuming that the radiators will be

heated by steam having a pressure of 5 pounds by the gauge, the outside temperature being 10° below zero. Let us sup-

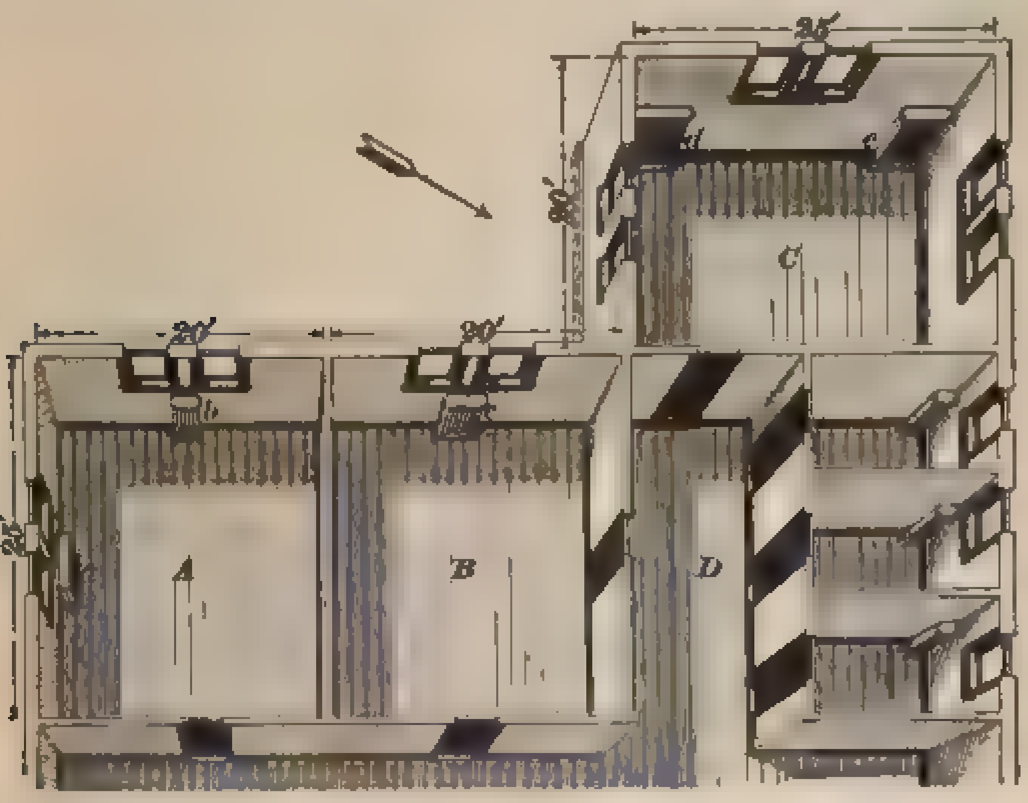


Fig. 48.

pose that the windows are each 6 ft. × 3 ft. and that the exposed walls are built of good ordinary brick, lathed and plastered inside.

Let S = number of square feet of radiating surface required to counteract the cooling effect of the glass and its equivalent in *exposed* wall surface;

t = difference in degrees F. between the desired temperature of the room and that of the external air;

t_1 = difference in degrees F. between the temperature of the heating surface and that of the air in the room;

s = number of square feet of glass and its equivalent in exposed wall surface.

Then, expressing rule 3, Art. **94**, as a formula, we get

$$S = \frac{t}{t_1} s.$$

When lathed and plastered brick walls are used, as in the figure, it is safe to estimate that about 10 square feet of wall surface will be equivalent in cooling power to 1 square foot of glass; consequently, in this case

$$\frac{\text{wall surface}}{10} = \text{equivalent glass surface.}$$

Let us commence with the room A; the amount of glass surface here is $6 \times 3 \times 4 = 72$ square feet. To this must be added the exposed wall surface reduced to a glass equivalent; thus,

$$\frac{10\,(25 + 20) - 72}{10} = 37.8 \text{ square feet.}$$

Since we assume that the inner walls, floors, and ceilings are not cooling surfaces, the only cooling surfaces we have to calculate against in the case of A is 72 square feet + 37.8 square feet = 109.8 square feet = s.

96. The temperature of steam at 5 pounds gauge pressure is 227°, and the difference between 70° above zero and 10° below zero is 70° + 10°; therefore, substituting in the formula, we have

$$S = \frac{70 + 10}{227 - 70} \times 109.8 = 56 \text{ square feet, nearly.}$$

This, however, only counteracts the cooling effect of the walls and windows, and to make reasonable allowance for air leakage, we will add 25 per cent. of the above amount, or 14 square feet, which gives us 56 + 14 = 70 square feet of direct radiating surface.

Now, suppose that we allow 20 per cent of the direct radiating surface (70 square feet in this case) for a moderate exposure to winds; the amount of heating surface, that is, the size of the radiator that we would place in A, will then be 70 + 14, or 84 square feet.

For convenience, we may divide this into two radiators, a having an area of 56 square feet and b an area of 28 square feet. This will so divide the radiator surface that one-third, or 28 square feet, may be used for duty during mild

weather; two-thirds, or 56 square feet, for moderate cold weather, and the whole, or 84 square feet, for use during severe weather.

In like manner and under the same conditions, we find that the sizes of the radiators *c*, *d*, and *e* should be, respectively, 40, 82, and 42 square feet.

As the coldest winds blow in the direction of the arrow, we place the 82-square-feet radiator in the left-hand exposed corner of the room *C*. A better distribution of the radiator surface in this room would be to make *d* 42 square feet only and place a radiator having 40 square feet between the windows towards which the arrow points; this will give a more uniform temperature to the room.

97. The reader will observe that *A*, *B*, and *C*, which are three rooms having the same shape and cubical contents, respectively, require 84 square feet, 40 square feet, and 124 square feet of heating surface, in order to maintain a temperature of 70° F. in each while the outer atmosphere is 10° below zero, and he will observe how imperfect must be the rule-of-thumb method of proportioning radiators to the cubical contents of the several rooms. Baldwin's rule should always be used where possible, in preference to the method described in Art. **92.**

OPERATING A HEATING PLANT.

98. A steam-heating plant really requires but little attention. All the engineer or janitor has to do with an ordinary system while it is in operation is to insure a steam pressure sufficient to produce good heating results. In ordinary cases this pressure is from 1 to 5 pounds by the gauge. He should inspect the system occasionally, at least once a month. In such an inspection he will invariably find that some radiator valves leak through the stuffingbox. These can easily be repacked without affecting the operation of the heating system, for by closing the radiator valve the steam pressure is taken off the stuffingbox. He

may find that some air vents "spit water" or blow steam when they really should be closed, because the radiators on which they are screwed are hot to the extreme end loop. These defective air vents should be immediately repaired or adjusted, as each case may require. If the inner parts are broken or irreparably defective, the engineer should replace the old vent with a new one; they are too cheap to waste much time on in repairs. The engineer should keep a stock of air vents on hand.

If when steam is on and the radiator valve open, the radiator does not heat, it is evident that the air valve is choked or otherwise closed so that it will not let out the air.

99. When a radiator valve is closed and a hissing or hammering noise is heard in the radiator, it is evident that the valve is not tight. A new disk, preferably of the Jenkins variety, should be put on. This requires shutting off steam from the riser line to which such a radiator is connected. If the radiator is connected on the two-pipe system, the return riser must also be shut off, otherwise the steam pressure may back up the water of condensation into the radiator through the returns and flood the building; or steam in the return riser will blow through the radiator and escape at the radiator valve when the bonnet is unscrewed.

100. Before replacing a valve stem and disk, it is proper to examine the valve seat carefully to see if it has a smooth, true face. If a groove has been ground out or the valve face is rough, it is advisable to grind it or to face it smooth and true with a reseating tool.

101. Before the steam is turned on a heating system in the autumn, all necessary repairs should be made and everything should be clean and ready for firing up at a moment's notice or for turning on steam from a power boiler or engine exhaust. The heating boilers, if any, should have been blown out and cleaned the preceding spring, when the system was put out of service for the summer. The return mains should all be drained clear at the same time. All valves should be examined and repaired, if

necessary, during the summer. This will prevent considerable trouble during the winter.

102. As floors and walls are liable to "settle," it is often necessary to readjust the steam-pipe hangers so that the grades of the pipes may be adjusted to prevent water hammer. This, also, should be attended to during the summer. Indeed, nearly all the attention that a heating system of the ordinary character requires is during the summer, when the engineer in charge of it usually has some spare time. And if a heating system receives proper attention during the summer, it should run all winter without repairs.

A SERIES

OF

QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS

TREATED OF IN THIS VOLUME.

It will be noticed that the Examination Questions that follow have been divided into sections, which have been given the same numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until that portion of the text having the same section number as the section in which the questions or examples occur has been carefully studied.

PUMPS.

(PART 1.)

EXAMINATION QUESTIONS.

(1) Why cannot a perfect vacuum be formed in the suction chamber of a pump ?

(2) Why can a suction pump at the bottom of a deep mine lift water higher than a pump at the surface ?

(3) Why is it difficult to pump hot water ?

(4) What do you understand by a direct-acting steam pump ?

(5) What governs the speed of a direct-acting pump ?

(6) What great objection to the single direct-acting steam pump does the duplex direct-acting steam pump overcome ?

(7) What is the peculiarity in the manner of operating the steam valves of a duplex direct-acting steam pump ?

(8) (*a*) Why is not the ordinary direct-acting pump an economical machine ? (*b*) How may its economy be increased ?

(9) In a Worthington slide-valve duplex pump, how is steam retained in the cylinder near the end of the stroke to form a cushion for the piston ?

(10) How do the dash relief valves of a Worthington steam pump control the length of the stroke ?

(11) (*a*) What is the purpose of the so-called cross-exhaust connection in compound direct-acting steam pumps ? (*b*) Explain its action.

(12) What is the purpose of the high-duty attachment to direct-acting steam pumps?

(13) (*a*) Briefly explain the principle of the high-duty attachment. (*b*) In what respect is the action of the high-duty attachment better than that of a flywheel?

(14) In a pump of the Leavitt design, what is gained by making the stroke of the plunger shorter than the stroke of the engine?

(15) Describe the Quimby screw pump in your own words.

(16) (*a*) On what does the action of a centrifugal pump depend? (*b*) To what classes of work are they particularly adapted?

(17) How are the cranks of duplex double-acting power pumps set so as to give a steady flow?

(18) If the supply of power is steady, why is the belt-driven pump the most economical pump to use?

(19) Why is the plunger pump the most common type of pump used in mines?

(20) What is a pit pump?

(21) What enables the steam to be used expansively in a Cornish pumping engine?

(22) What advantages does the Bull pumping engine possess over the Cornish pump?

(23) Mention some of the objections to lift pumps when used for mining purposes.

(24) What terms are usually applied to the suction pipe and the delivery pipe of pit pumps?

(25) What is meant by a sinking pump?

(26) What are the advantages of the pulsometer?

(27) Mention some of the advantages claimed for the Pohlé air lift.

(28) Briefly describe the principle and action of a differential pump.

(29) What is the particular feature of the Riedler express pump that allows the pump to be run at such high speeds?

PUMPS.

(PART 2.)

EXAMINATION QUESTIONS.

(1) (*a*) How are the plungers of pumps used for moderate pressures usually packed? (*b*) How are they packed when used for heavy pressures?

(2) Mention two important disadvantages of the inside-packed plunger pump.

(3) What is meant by the valve deck of a pump?

(4) What is the object of curving the wings of wing valves?

(5) Why are air chambers used on the discharge pipes of pumps?

(6) (*a*) Briefly describe an alleviator and (*b*) state why they are used instead of air chambers.

(7) Why are vacuum chambers sometimes required on the suction pipe of pumps?

(8) In setting up a pump with steam-thrown valves, what precautions should be taken in order to have the valves work properly?

(9) What precautions should be taken in designing the suction pipe?

(10) (*a*) What is a foot-valve and (*b*) what is its purpose?

(11) Why is it a good plan to use a relief valve on a suction pipe that is fitted with a foot-valve?

(12) In what ways may sand and grit held in suspension in the suction water be removed before entering the pump?

(13) What is the object of placing a check-valve in the delivery pipe near the pump?

(14) Explain how a water-end by-pass can aid in starting a compound steam pump.

(15) Why is it that a pump will sometimes refuse to start when air is in the pump chamber and the full pressure is on the delivery valves?

(16) Mention some of the causes of loss in efficiency of steam pumps.

(17) Describe the manner of removing the dirt and grit from the piping and cylinder and valve seats of a new steam pump.

(18) In starting a new direct-acting steam pump with dash relief valves, what precaution should be taken with regard to the relief valves?

(19) Mention some of the causes of trouble with the suction end.

(20) (*a*) In pumping hot water, if the pump works with a jerky action, what is the trouble? (*b*) How may this jerky action be stopped?

(21) If the pump pounds at the beginning of the stroke when running fast, what is probably the trouble with the suction end?

(22) (*a*) What is the effect of too little lost motion between the valve stem and valve of a duplex pump? (*b*) What is the effect of too much lost motion?

(23) How may leaks in the suction pipe be detected?

(24) How can small pinholes in the delivery pipe be stopped up?

(25) How are air chambers usually tested for leaks?

(26) Will an air chamber aid in preventing surging in long delivery pipes?

(27) Why is surging in the suction pipes not so serious as in the delivery pipes?

(28) In pumping a mixture of water and air, how may the air be removed from the water before reaching the pump?

(29) Describe the method of setting the valves of a duplex steam pump.

PUMPS.

(PART 3.)

EXAMINATION QUESTIONS.

(1) How is the mean effective area of a double-acting piston pump found?

(2) Explain how the actual discharge of a pump may be greater than the piston displacement.

(3) What is the probable horsepower required to discharge 1,200 cubic feet of water per hour against a pressure of 125 pounds per square inch? Ans. 15.56 H. P.

(4) What is meant by the piston speed of a pump?

(5) If a pump is to discharge 94,000 pounds of water per hour, what should be the diameter of the pump plunger, its speed being 85 feet per minute? Ans. 8.22 in., nearly.

(6) (*a*) Mention three ways in which the duty of a steam pump may be stated and (*b*) compare their relative merits.

(7) The plunger of a single double-acting pump is 24 inches in diameter and the plunger rod is $3\frac{1}{2}$ inches in diameter. The plunger makes 35 strokes per minute, the length of stroke being 36 inches. What is the displacement in Winchester gallons per hour?

Ans. 146,478 gal. per hr.

(8) A single-acting plunger pump has a plunger 10 inches in diameter and a stroke of 30 inches. If the pump makes

40 discharging strokes per minute and discharges 48.3 cubic feet of water, what is the slip? Ans. 11.4 per cent.

(9) If a duplex double-acting pump has plungers 8 inches in diameter and makes 35 strokes per minute, how many Winchester gallons may the pump be expected to deliver per minute the length of stroke being 30 inches?

Ans. 182.9 gal. per min.

(10) If a pump requires 20 pounds of coal to raise 975 cubic feet of water 140 feet, what is the duty of the pump per 100 pounds of coal? Ans. 42,656,250 ft.-lb.

(11) Explain how the increased size of pipes and passages of large pumps increases the efficiency of the pumps.

(12) Approximately, how many cubic feet of water per minute can a 40-horsepower engine discharge at a height of 96 feet? Ans. 154 cu. ft.

(13) As usually stated, how does the efficiency of a rotary or centrifugal pump differ from the efficiency of a reciprocating steam pump?

(14) If it is desired to pump water against a pressure of 350 pounds per square inch, what should be the minimum diameter of the steam piston for a pump having a plunger 9 inches in diameter, the available steam pressure being 90 pounds per square inch? Ans. 21.1 in.

(15) (*a*) Mention some of the merits of rotary pumps. (*b*) For what class of work are they particularly adapted?

(16) About what horsepower will be required to discharge 48 cubic feet of water per minute, the total lift being 188 feet? Ans. 24.4 H. P.

(17) What is one serious objection to the use of steam driven crank-and-flywheel pumps for boiler feeding?

(18) A double-acting pump has a plunger 26 inches in diameter and 44 inches stroke. The plunger has a piston rod 4 inches in diameter extending through both pump cylinder heads. During a 12-hour duty trial the total heat supplied in the steam to the engine was 188,765,300 B. T. U. and the pump made 64,800 strokes. If the average pressure

indicated by a gauge on the discharge pipe was 160 pounds, the average vacuum indicated by a gauge on the suction pipe 10 inches, and the difference in level between the centers of the vacuum gauge and the pressure gauge 12 feet, what was the duty of the pump? Ans. 110,996,971 ft.-lb.

(19) If the water piston of a pump is 6 inches in diameter and moves at a speed of 85 feet per minute, what will be the velocity of the water in the delivery pipe if the latter is $2\frac{1}{2}$ inches in actual diameter? Ans. 489 ft. per min.

(20) Estimate the pressure against which a 35-horsepower pump can discharge 62.5 cubic feet of water per minute.

Ans. 90 lb., nearly.

(21) Why is it necessary to make the water end of a flywheel pump heavier than the water end of a direct-acting pump?

(22) Approximately, at what height will a pump driven by a 25-horsepower engine discharge 180 cubic feet of water per minute? Ans. 51.3 ft.

(23) Find the areas of the suction and discharge pipes for a duplex double-acting pump that is to discharge 66,000 cubic feet of water per hour.

Ans. { Suction pipe 792 sq. in.
{ Delivery pipe 316.8 sq. in.

(24) Estimate the number of Winchester gallons of water a pump of 75 horsepower will deliver per minute against a pressure of 150 pounds per square inch.

Ans. 602 gal. per min.

(25) If a pump lifted 128,000 cubic feet of water 85 feet with 7,280 pounds of steam, what was the duty per 1,000 pounds of dry steam? Ans. 93,406,593 ft.-lb.

(26) Roughly estimate the discharge in gallons of a double-acting pump with an 8-inch plunger.

Ans. 208.64 gal. per min.

(27) What is the principal difference between general-service pumps and tank or light-service pumps?

(28) As generally constructed, what is the distinguishing feature of pressure pumps with regard to the plunger arrangement?

(29) If the piston speed is 96 feet and the number of delivery strokes 48 per minute, what should be the length of the stroke? Ans. 2 ft.

(30) Mention some of the distinguishing features of the modern high-pressure mine pumps.

(31) How are the valves of sewage pumps frequently made so as to allow large objects to pass through the pump?

(32) Mention one advantage of the electrically driven pump when used for mining purposes.

(33) What do you understand by dry and wet vacuum pumps?

(34) (a) In compound and triple-expansion direct-acting duplex pumps, what is the usual degree of expansion obtained? (b) How is this ratio sometimes increased?

(35) To what is the high duty of the crank-and-flywheel pump due?

ELEVATORS.

(PART 1.)

EXAMINATION QUESTIONS.

(1) How are elevators usually classified with reference to the motive power used?

(2) What is meant by a corner-post elevator?

(3) What do you understand by the term "drum type" of elevator?

(4) In the drum type of elevator, how is the rope, as it winds upon the drum, prevented from jumping the grooves of the drum by its deflection?

(5) (*a*) What do you understand by overbalancing an elevator? (*b*) What type of elevator cannot be overbalanced? (*c*) Why?

(6) What is the advantage of overbalancing an elevator?

(7) How may the change in the counterbalancing due to the weight of the rope when the car is in different positions be compensated?

(8) What are the objections to the simple shipper rope for operating an elevator?

(9) Into what two classes may safety devices be divided?

(10) In what two forms is the motor of the hand elevator usually represented?

(11) Are hand elevators usually overbalanced or underbalanced, if they are balanced at all?

(12) Why should all elevators be started and stopped gradually?

(13) (*a*) Why are wire ropes used in elevator work made with hemp centers? (*b*) When should a wire rope be condemned as dangerous?

(14) Mention three preparations for lubricating wire ropes.

(15) In fastening the rope to the drum, what precaution should be observed in order to reduce the stress at the point of fastening?

(16) Why should not the guides be allowed to become gummy?

(17) What do you understand by the term belt elevator?

(18) Why are worm-geared belt elevators usually overbalanced while spur-geared ones are not?

(19) How are the limit stops on the shipper rope of belt elevators usually made?

(20) Briefly describe the principle of the most common form of motor limit stop.

(21) What provision is usually made on elevators to prevent the cable from unwinding should the car stick in its descent?

(22) In worm-geared elevators how may the end thrust due to the use of a worm be avoided?

(23) What is the maximum speed at which belt elevators should be run?

(24) In worm-geared elevators what lubricant should be used for the worm bath?

(25) In general, what precautions should be taken in the maintenance of belt elevators?

(26) Explain briefly the principle of the mechanism for reversing the engines of an Otis spur-gear steam elevator.

(27) What is the general principle of the slack-cable safety provided on all steam elevators?

ELEVATORS.

(PART 2.)

EXAMINATION QUESTIONS.

(1) Mention (*a*) the different kinds of electric motors used in elevator service, and (*b*) the service to which each is particularly adapted.

(2) Why should the main switch be closed with all the starting resistance in the armature circuit ?

(3) Briefly describe the operation of the rheostat shown in Fig. 1 of the text.

(4) In the reversible switch shown in Fig. 5 of the text, how may sparking at the clips connected to the shunt field be prevented when the circuit is being opened ?

(5) (*a*) What do you understand by a solenoid rheostat ? (*b*) What is one advantage of this type of rheostat ?

(6) What two important conditions must be fulfilled by the motor of a direct-connected electric elevator ?

(7) What are the only alternating-current motors that are satisfactory for direct-connected electric elevators ?

(8) Are direct-connected electric elevators of the drum type over or under counterbalanced ?

(9) In electric elevators, by what different means may the brake be operated ?

(10) (*a*) Briefly describe the simple controller used by the Elektron Manufacturing Company. (*b*) What is the

reason for turning the shipper sheave through such a wide angle in order to reverse the motor?

(11) In the electrical-mechanical brake used by the Elektron Manufacturing Company, how is the rapidity of action of the brake controlled?

(12) Briefly describe what takes place when the above elevator is started or stopped.

(13) Describe the principle of the dynamic brake made by the Elektron Manufacturing Company.

(14) (*a*) When a dynamic brake is used, why is the field kept excited after the armature circuit is broken and the armature short-circuited? (*b*) How is this done in the Elektron Manufacturing Company's brake?

(15) (*a*) What is the peculiarity of the step bearing used on the A. B. See elevator shown in Fig. 17 of the text? (*b*) What is the advantage of this arrangement?

(16) What motor safeties are applied to the A. B. See elevator?

(17) (*a*) In the Otis single-worm elevator, how is an increased thrust-bearing surface obtained without increasing the size of the shaft? (*b*) How is the pressure between the bearing surfaces equalized?

(18) What is the object of the safety magnet used on the Otis elevator?

(19) (*a*) In the Otis high-speed elevators, what provision is made for stopping the elevator almost instantly when the limits of travel are reached? (*b*) How is the operating device arranged to prevent accidental reversal of the motor in stopping?

(20) What is the use of the potential switch made by the Otis Company?

(21) Briefly describe the potential switch as it is made when it only operates when the current falls below the normal.

(22) (*a*) Give the general features of the magnet-control method of operating elevators. (*b*) What are its advantages over the rheostat method?

(23) Explain the operation of the Otis G. S. controller when the handle of the car controlling switch is moved to the "fast down" position.

(24) (*a*) What is the main difference between the Otis G. S. magnet controller and the No. 6 controller? (*b*) Explain the action of the No. 6 controller when the handle of the operating switch is moved to the "down" position.

(25) (*a*) Describe briefly the operation of the Otis automatic elevator with older style floor controller when the car is at the first floor and the button on the fourth floor is pressed. Also, when the passenger enters the car and pushes the button to descend to the second floor. (*b*) Show how the circuits are arranged so that the movements of the elevator cannot be interfered with when it is already in use.

(26) Describe briefly the operation and distinctive features of the Sprague-Pratt electric elevator.

(27) Explain the operation of the Fraser differential-speed elevator.

ELEVATORS.

(PART 3.)

EXAMINATION QUESTIONS.

(1) What are some of the advantages and disadvantages of hydraulic elevators ?

(2) (*a*) What do you understand by a plunger elevator ? (*b*) For what kinds of service are they mostly used ?

(3) Why cannot plunger elevators be overbalanced ?

(4) In a balanced plunger elevator, what would happen if the car became loose from the plunger ?

(5) How is it that the controlling valve in a hydraulic elevator acts as a power control and brake at the same time ?

(6) How may the rapid descent of a plunger elevator be provided against should the controlling valve fail to work ?

(7) What is the principal advantage of the piston elevator over the plunger elevator ?

(8) In vertical piston elevators in which the cylinder is always full of water, why is it preferable to put as much of the counterweight as is possible directly on the piston or piston rods ?

(9) (*a*) What is the object of making the water circulate from the top to the bottom of the piston in vertical piston elevators ? (*b*) Explain your answer.

(10) What is the object of placing a relief valve in the discharge pipe between the cylinder and the controlling valve?

(11) (*a*) What is the purpose of the pilot valve? (*b*) Why is its use necessary in high-speed elevators?

(12) Explain the use of the throttle placed between the upper and lower pistons of the main controlling valve.

(13) (*a*) What do you understand by a double-power hydraulic elevator? (*b*) Where are they used?

(14) In hydraulic elevators in which the ratio of car travel to piston travel is very high, the water is admitted to but one side of the piston. Why is this done?

(15) What are the principal advantages of horizontal hydraulic piston elevators over vertical hydraulic piston elevators?

(16) What do you understand by the terms "tension type" and "compression type" as applied to horizontal hydraulic piston elevators?

(17) In the horizontal tension type, why is the short distance required between the sheaves a decided advantage?

(18) When a closed pressure tank is used, how is the pressure within the tank kept practically constant while the elevator is in operation?

(19) (*a*) In what ways may the air escape from closed pressure tanks? (*b*) How is it replenished?

(20) Briefly describe the Ford regulating valve.

(21) How is the Ford regulating valve modified so as to operate the switch and rheostat of an electric motor?

(22) What is the object of using a by-pass valve to open a communication between the suction and delivery pipes of the pressure pump?

(23) If the absorption of the air by the water in the pressure tank is excessive, how may it be prevented?

(24) In filling the pressure tank, how may sufficient air be introduced to give the required pressure ?

(25) If a large quantity of air collects in the cylinder, how may it be removed ?

(26) In what manner will a worn or leaking piston packing indicate itself ?

(27) Briefly describe an effective method of lubricating the internal parts of elevator plants.

(28) In the vertical circulating hydraulic elevator, how may the water be removed from the cylinder and circulating pipe ?

(29) Briefly describe the necessary steps in packing a vertical cylinder piston from the top.

(30) If the cylinder of a horizontal hydraulic elevator is badly worn, how should the piston be packed ?

(31) If the packing used is made of cotton, how should it be treated to remove the air from the pores ?

ELEVATORS.

(PART 4.)

EXAMINATION QUESTIONS.

(1) Mention some of the means by which car safeties are set in operation.

(2) (*a*) For what kind of elevators is the pawl-and-ratchet safety suitable? (*b*) By what arrangement is the pawl and ratchet usually replaced?

(3) Why is it necessary to attach each cable to a separate wedge-operating lever when a gravity-wedge safety is used?

(4) (*a*) In high-speed elevators, what else besides a broken or a slack cable is usually made to operate the safety devices? (*b*) By what apparatus is this usually accomplished?

(5) Briefly describe how the governor on an Otis elevator applies the car safety.

(6) When a safety drum is used, what is the object of also having a governor-controlled brake?

(7) Why should not the guides be allowed to become gummy?

(8) Before unlocking the safety after it has been set, what precaution should be taken?

(9) If a car has been stopped above the top landing by a wedge-safety device, how would you proceed to lower the car?

(10) Briefly describe the air-cushion safety and its operation.

(11) (*a*) In the air-cushion safety, what should be the depth of the pit compared with the height of the lift? (*b*) In high lifts, how is this depth of pit obtained?

(12) (*a*) Mention some of the objections to solid walls or partitions for elevator shafts. (*b*) If the partitions are not carried to the ceilings, how high should they be?

(13) Mention some of the requirements of elevator doors.

(14) In some elevators, how is the car prevented from starting before the door is closed?

(15) In passenger service, how is the movement of the car sometimes indicated to the would-be passengers?

(16) For what class of service are escalators particularly adapted?

STEAM HEATING.

EXAMINATION QUESTIONS.

(1) Describe briefly the one-pipe system of steam heating and explain how the water of condensation is returned to the boiler.

(2) What is the principal difference between the one-pipe, two-pipe, separate-return, and drop systems of heating?

(3) Mention some of the defects of the one-pipe system of heating.

(4) About what pitch are main steam pipes usually given?

(5) In case a horizontal pipe is too long to be given a uniform grade for drainage purposes, how can it be drained?

(6) (*a*) Should a long riser be connected directly to the top of the steam main by a **T**? (*b*) Why?

(7) Explain how a radiator in a one-pipe system may become filled with water.

(8) What is the objection to a return main located above the water level?

(9) What diameter of main steam pipe is required to supply direct radiators having a total heating surface of 5,000 square feet? Ans. 8-in. pipe.

(10) What is the usual amount of expansion allowed for in steam piping?

(11) If a pipe 6 inches in diameter is used, what amount of direct heating surface may be supplied by it?

Ans. 2,827.4 sq. ft.

(12) In what two ways should a system of piping be tested before it is covered by plastering or flooring ?

(13) (*a*) What is the object of making radiators with extended surfaces ? (*b*) Has a radiator with extended surfaces any advantage over a radiator having plain surfaces, if the air is simply moved by convection ?

(14) Explain why the most effective form of radiator or coil for direct heating is one having a single row of tubes placed in a horizontal position.

(15) What are the advantages of flue radiators with regard to efficient heating surface ?

(16) (*a*) If a flat heating coil is to be used with the row of tubes placed vertically, why should not the opposite ends of the tubes screw directly into manifolds ? (*b*) How should the coil be constructed ?

(17) Describe the Nason tube.

(18) How may a radiator of the Bundy type be adapted to direct-indirect heating ?

(19) In a two-pipe system, why should the return riser be shut off when the valve in the steam riser is closed ?

(20) If it is necessary to place two radiators in one room, why is it a good plan to divide the total heating surface required between the radiators, so that one will be, say, twice as large as the other ?

(21) How many square feet of heating surface should a radiator have to heat a room that is 20 feet wide, 30 feet long, and 10 feet high ? There are two exposed walls (a side and an end) and three windows $3\frac{1}{2}$ ft. $\times$ 6 ft. The lowest outside temperature is 0° F., the temperature of the steam used is 225° F., and the temperature of the room is to be 70° F. The walls are of brick and are lathed and plastered. Allow 30 per cent. for air leakage and 25 per cent. for exposure to winds. Ans. 78.4 sq. ft.

(22) If a hammering or hissing sound is heard in a raditor when the valve is closed, what is probably the trouble ?

(23) If a radiator does not heat when the steam is turned on, what is out of order ?

(24) Where should the air vent be placed on a radiator with reference to the steam inlet ?

(25) (*a*) What is the principal objection to the ordinary air vent ? (*b*) How may it be remedied ?

(26) What can you say as to the beneficial results obtained by injecting cold feedwater into the receiver of a vacuum system to improve the vacuum ?

A KEY

TO ALL THE

QUESTIONS AND EXAMPLES

INCLUDED IN THE

EXAMINATION QUESTIONS IN THIS VOLUME.

It will be noticed that the Key is divided into sections which correspond to the sections in the Examination Questions in this Volume. The answers and solutions are so numbered as to be similar to the numbers before the questions to which they refer.

PUMPS.

(PART 1.)

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(1) On account of mechanical imperfections, air contained in the water, and the vapor of the water itself. See Art. **6.**

(2) Because the atmospheric pressure at the bottom of the mine is greater than at the surface. See Art. **7.**

(3) Because the increased vapor pressure at the higher temperatures counteracts the pressure of the atmosphere. See Art. **8.**

(4) A steam pump in which the pressure of the steam in the steam cylinder is transferred to the pump piston or plunger in a straight line. See Art. **14.**

(5) The difference between the power exerted in the steam cylinders and the resistance in the pump. See Art. **14.**

(6) The intermittent motion of the column of water being pumped. See Art. **15.**

(7) The steam valves of each pump are driven by the piston rod of the opposite pump. See Art. **16.**

(8) (*a*) Because it is necessary to carry the full steam pressure the full length of the stroke. See Art. **18.**

(*b*) By compounding the steam end, or by the use of a high-duty attachment, or both. See Art. **18.**

(9) There is an exhaust port and steam port for each end of the cylinder. The exhaust port is some distance from the end of the cylinder, so that the piston covers it before the end

of the stroke, thus confining some steam in the cylinder to act as a cushion. See Art. **25.**

(10) The dash relief valves control a passage between the steam and exhaust ports and are so set that at the highest speed of the pump there will be sufficient compression to prevent the piston striking the cylinder heads. As the speed becomes slower, the compression remaining the same, the piston would stop short of the full stroke, if it were not that the dash relief valves allow the compressed steam to escape through the steam port, thus allowing the piston to complete its stroke. See Art. **28.**

(11) (*a*) To keep a more uniform pressure in the steam chests of the low-pressure cylinders. See Art. **34.**

(*b*) The steam chests of the low-pressure cylinders are joined by a pipe that allows the exhaust from the high-pressure cylinders to pass to either of the low-pressure cylinders. When the pressure begins to drop in one low-pressure steam chest, the pressure is highest in the opposite low-pressure steam chest, and as the two steam chests are connected, the steam pressure is nearly equalized in both. See Art. **34.**

(12) It allows the steam to be cut off early in the cylinders, thus allowing the steam to be used expansively. See Art. **36.**

(13) (*a*) The high-duty attachment, as usually made, consists of two compensating cylinders having their plungers attached to opposite sides of the pump crosshead. These cylinders are connected to an accumulator through hollow trunnions, on which they oscillate as the pump crosshead moves backwards and forwards. At the beginning of the stroke the plungers are forced into the compensating cylinders, thus creating a pressure in the accumulator, but after the pump crosshead has passed the center of its stroke the angle between the compensating plungers and the pump piston rod becomes such that the plungers are forced out and thus aid in completing the stroke. See Arts. **36** and **37.**

(*b*) The results obtained are independent of the speed. See Art. **38.**

(14) It allows the steam pistons to work at a higher speed, which is a decided advantage in many respects. See Art. **44.**

(15) The Quimby pump has two shafts placed side by side and connected by gears. Each shaft has a right-handed and left-handed screw, the right-handed screw of one shaft meshing with the left-handed screw of the other shaft. The screws fit the casing closely and are a close running fit on each other. The water passes through passages in the casing to the water ends of the screws and is then drawn towards the center by the revolving screws and is discharged through the discharge pipe. See Art. **48.**

(16) (*a*) On the pressure produced by the centrifugal force of a quantity of water rotated by the vanes of the pump. See Art. **49.**

(*b*) They are particularly adapted to low heads where large quantities of water are to be pumped and also where water containing large quantities of mud, sand, and gravel is to be handled. See Art. **50.**

(17) 90° apart. See Art. **53.**

(18) Because they get their power with the same efficiency as the engine from which they are driven. See Art. **56.**

(19) Because the leakage can be easily stopped and the plunger type is best adapted to high pressures. See Art. **58.**

(20) A pit pump is a pump having its water end located at the bottom of the mine and connected to a steam engine or other motor at the surface. See Art. **59.**

(21) The momentum of the pit work is sufficient to complete the stroke after the steam is cut off; this allows the steam to be used expansively. See Art. **61.**

(22) The heavy walking beam and its connections are dispensed with, the first cost is less, there is less friction, and the advantage of a direct-acting engine is obtained See Art. **63.**

(23) The pump rod reduces the effective area of the pipe and increases the friction of the water. The rods are concealed and cannot be readily inspected. When the rods or bolts break, it is difficult to recover them. When pumping against a heavy pressure, it is impossible to keep the piston tight. See Art. **67.**

(24) The suction pipe is called the wind bore and the delivery pipe the working barrel. See Art. **68.**

(25) When putting down a new shaft or deepening an old one, the pump used to drain the water from the shaft bottom is called a sinking pump. See Art. **71.**

(26) It has no wearing parts except the valves, which are easily and cheaply repaired. It will work in any position and requires no attention when once started. There are no parts to get out of order and it will pump anything that can get past the valves. See Art. **86.**

(27) It has no moving parts and is not affected by sand or grit. The action of the air purifies the water and cools it as it is being pumped. It is also claimed to increase the flow of a well. The full area of the well is available for a flow of water. See Art. **88.**

(28) The differential pump has two pistons whose displacements are in the ratio of 2 to 1 The larger piston works in the suction chamber and the smaller piston in the delivery chamber. When the large piston enters the suction chamber, it forces into the delivery chamber a volume of water equal to its displacement, but at the same time the small plunger has withdrawn from the delivery chamber a volume equal to half the large plunger displacement. Thus the amount of water actually discharged is equal to the difference in the displacement of the two plungers, or equal to

the displacement of the small plunger. On the return stroke the small plunger discharges an amount equal to its displacement and at the same time double the amount of water is drawn into the suction chamber. See Arts. **94** and **95.**

(29) The suction valve, which is positively seated just before the end of the suction stroke by a buffer on the water plunger. See Art. **102.**

PUMPS.

(PART 2.)

(1) (*a*) With hemp contained in a stuffingbox of the ordinary pattern. See Art. **3.**

(*b*) With a **U**-shaped leather packing held in a recess in the upper end of the pump cylinder. See Art. **4.**

(2) When the packing becomes worn, the heads of the pump cylinder must be removed to tighten or renew it, and there is no way of detecting leakage when the pump is working. See Art. **5.**

(3) The part of the pump chamber that contains the valves. See Art. **14.**

(4) To give the valve a partial rotation at each stroke of the pump so that it will wear its seat evenly. See Art. **20.**

(5) To relieve the pipes and pump of shocks by promoting a uniform flow of water. See Art. **23.**

(6) (*a*) An alleviator is simply a plunger working in a cylinder through a stuffingbox; the plunger is forced into the cylinder by springs or rubber buffers. The cylinder communicates with the delivery pipe of the pump and thus acts the same as an air chamber. See Art. **28.**

(*b*) When pumps work against high pressures, the air in the air chambers is rapidly absorbed by the water or escapes from the air chamber, thus rendering it useless. For this reason alleviators are used. See Art. **28.**

(7) To promote a prompt flow of the water into the pump chamber. See Art. **29.**

(8) The foundation surface should not be winding nor should the steam or water pipes be sprung into place, else the valves will be liable to stick. See Art. **39.**

(9) The suction pipe should be as straight as possible, and if bends are necessary they should be of large radius. It should be of one size from end to end, and if very long it should be somewhat larger than is necessary to keep the velocity of flow down to 200 feet per minute. If the lift is high, a suction chamber and a foot-valve should be provided. See Art. **41.**

(10) (*a*) A foot-valve is a check-valve placed at the lower end of the suction pipe and opening towards the pump. See Art. **42.**

(*b*) Its purpose is to prevent the suction pipe emptying while the pump is standing and to prevent the water in the suction pipe slipping back while running. See Art. **42.**

(11) Because if the suction valves leak or if the priming pipe is left open, the full pressure of the delivery water will come on the suction pipe, which is usually not designed to withstand such a high pressure. See Art. **43.**

(12) By means of a settling chamber, a suction basket, a strainer, or a special form of strainer consisting of perforated plates placed in the suction pipe near the pump cylinder. See Arts. **44** and **45.**

(13) To relieve the pump of pressure when starting up, so that it will take hold of the water more readily, and to hold back the water in case of repairs. See Art. **46.**

(14) By opening the by-pass the pressure on the plungers can be relieved for a sufficient number of strokes to allow steam to enter the low-pressure cylinder, thus rendering the full power of the steam end available for pumping. See Art. **48.**

(15) The air is not dislodged but only compressed and expanded again with the motion of the piston ; thus no vacuum is formed and the pump will not start. See Art. **52.**

(16) Wear, improper adjustments, wrong timing of the movements of the steam valve, leakage, lack of alinement, and foreign matter in the suction and foot-valves and suction and delivery pipes. See Art. **58.**

(17) The pistons, valves, and cylinder heads are removed, and as the steam pressure rises in the boiler it is allowed to blow through, thus thoroughly cleaning the piping. Before the working pressure is reached, the stop-valves are closed and the cylinder heads put on and the stuffingboxes closed, leaving the pistons and valves still out of the cylinders. The steam at full working pressure is then turned on, which thoroughly removes all dirt and grit from the valve seats and cylinders. Any dirt found in the corners of the cylinders should then be removed by hand. See Arts. **63** and **64.**

(18) The dash relief valves should be closed in order to keep the piston as far from the cylinder heads as possible. See Art. **72.**

(19) Leaks at the joints or along the suction pipe or in the pump chamber, which may be caused by imperfect connections, leaky chaplets, shifted cores, blowholes, corrosion, or cracks from frost. See Art. **76.**

(20) (*a*) The lift is too high for the temperature of the water. See Art. **77.**

(*b*) By decreasing either the lift or the temperature. See Art. **77.**

(21) The pump chamber is not filling and the plunger is striking the incoming water on its return stroke. See Art. **78.**

(22) (*a*) Short stroking. See Art. **83.**

(*b*) The piston will strike the heads. See Art. **83.**

(23) By the ear, by the flame of a candle, or by stopping the lower end of the suction pipe and putting a pressure of 40 or 50 pounds per square inch on it. See Art. **85.**

(24) By spreading a thick layer of red-lead putty over the leaks and then wrapping several layers of canvas covered with red-lead putty on both sides tightly about the pipe. See Art. **88.**

(25) By closing all openings and then pumping air into them until the working pressure is reached. If the chambers are tight, the air pressure should show no reduction in 24 hours. See Art. **90.**

(26) No; they probably aggravate the trouble by forming a cushion from which the column of water rebounds. See Art. **97.**

(27) Because the direction of the force resulting from surging in the suction pipe is in the natural direction of flow of the water and simply tends to open the pump valves, while the shock due to surging in the delivery pipe comes against the valves and must be withstood by the machinery. See Art. **99.**

(28) By connecting an air pump to the suction air chamber. See Art. **102.**

(29) Move the pistons until they strike the cylinder heads and make a mark on the piston rod at the end of the steam-end stuffingbox gland. Move the pistons until they strike the opposite cylinder heads and make another mark on the piston rod. Then make a mark half way between these two marks and move the pistons until these central marks come even with the end of the stuffingbox gland. Now set the valves central over the ports and adjust the locknuts so as to allow the same lost motion on each side of the valve. See Art. **103.**

PUMPS.

(PART 3.)

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(1) The mean effective area is equal to twice the piston area diminished by the area of the piston rod, and the difference divided by 2. See Art. **4.**

(2) When the suction and discharge pipes are long and the lift moderate, there may be sufficient energy imparted to the column of water during the discharge stroke to keep it in motion during the return stroke. Under these conditions the actual discharge may be larger than the displacement. See Art. **8.**

(3) Reducing the volume per hour to pounds per minute, we have

$$\frac{1{,}200 \times 62.5}{60} = 1{,}250 \text{ pounds per minute.}$$

Applying rule 4, Art. **15,** we have

$$H_e = \frac{1{,}250 \times 125}{10{,}043} = 15.56 \text{ H. P.} \quad \text{Ans.}$$

(4) The number of feet traveled per minute by the plunger when discharging water. See Art. **20.**

(5) Reducing the weight of water discharged per hour to cubic feet discharged per minute, we have

$$\frac{94{,}000}{62.5 \times 60} = 25.07 \text{ cubic feet.}$$

Applying rule **9**, Art. **22**, we get

$$d = \sqrt{\frac{229 \times 25.07}{85}} = 8.22 \text{ in., nearly. Ans.}$$

(6) (*a*) The duty may be stated as the number of foot-pounds of work done per 100 pounds of coal burned, or per 1,000 pounds of dry steam, or per 1,000,000 B. T. U. supplied. See Arts. **35**, **36**, and **38**.

(*b*) Duty based on the coal consumption gives an idea of the coal required by a pump of a given type for the performance of a given quantity of work, but it does not give reliable results when the duty of pumps of different types working under different conditions are to be compared. The basis of 1,000 pounds of dry steam is better adapted to duty trials, but it is open to the objection that the pressure of the steam is not taken into consideration. The heat-unit basis is the most scientific and the most accurate for comparative purposes, as the duty is based on the exact amount of heat energy consumed by the pump. See Arts. **35**, **37**, and **38**.

(7) The mean effective area of the plunger is

$$\frac{24^2 \times .7854 + (24^2 \times .7854 - 3\tfrac{1}{2}^2 \times .7854)}{2}$$
$$= 447.58 \text{ square inches.}$$

Applying rule **1**, Art. **3**, we have

$$D_{av} = \frac{36 \times 447.58 \times 35}{231} = 2{,}441.3 \text{ gal. per min.,}$$

or $$2{,}441.3 \times 60 = 146{,}478 \text{ gal. per hr. Ans.}$$

(8) By rule **1**, Art. **3**, the displacement is

$$\frac{30 \times 10^2 \times .7854 \times 40}{1{,}728} = 54.54 \text{ cubic feet.}$$

By rule **2**, Art. **8**, the slip is

$$\frac{(54.54 - 48.3) \times 100}{54.54} = 11.4 \text{ per cent. Ans.}$$

(9) The piston speed is $\frac{30}{12} \times 35 = 87.5$ feet per minute. Applying rule **10**, Art. **23**, we have

$$D = \frac{8^2 \times 87.5}{229} = 24.45 \text{ cu. ft. per min.,}$$

or $$\frac{24.45 \times 1,728}{231} = 182.9 \text{ gal. per min.} \quad \text{Ans.}$$

(10) The weight of water pumped is $975 \times 62.5 = 60,937.5$ pounds. By rule **14**, Art. **34**, we get

$$D = \frac{100 \times 60,937.5 \times 140}{20} = 42,656,250 \text{ ft.-lb.} \quad \text{Ans.}$$

(11) Increasing the size of pipes and passages reduces the relative amount of friction surface exposed per unit volume of water delivered, thus increasing the efficiency. See Art. **49.**

(12) By rule **6**, Art. **17**, we have

$$W = \frac{23,100 \times 40}{96} = 9,625 \text{ lb.,}$$

or $$\frac{9,625}{62.5} = 154 \text{ cu. ft. per min.} \quad \text{Ans.}$$

(13) The efficiency of a rotary or centrifugal pump is the efficiency of the pump itself and not of the pump and engine, as in the case of a steam pump. See. Art. **50.**

(14) The area of the plunger is $9^2 \times .7854 = 63.62$ square inches. By rule **13**, Art. **28**, we get

$$d_m = \sqrt{\frac{1.8 \times 63.62 \times 350}{90}} = 21.1 \text{ in.} \quad \text{Ans.}$$

(15) (*a*) Rotary pumps are light, simple, and inexpensive, and occupy relatively but little space for their capacity. They require but little or no foundation. See Arts. **55** and **56.**

(*b*) They are particularly adapted to pumping water holding soft material in suspension. See Art. **55.**

(16) The weight of water to be pumped per minute is $48 \times 62.5 = 3{,}000$ pounds. Applying rule **3**, Art. **14**, we get

$$H_e = \frac{3{,}000 \times 188}{23{,}100} = 24.4 \text{ H. P.} \quad \text{Ans.}$$

(17) They cannot always be run slow enough to suit the demand without stopping on the centers.

(18) The mean effective area of each end of the plunger is $26^2 \times .7854 - 4^2 \times .7854 = 518.36$ square inches. The pressure corresponding to a vacuum of 10 inches is $p = 10 \times .4914 = 4.91$ pounds per square inch, and the pressure corresponding to a difference in level of 12 feet is $s = 12 \times .434 = 5.21$ pounds per square inch. The stroke is $\frac{45}{12} = 3\frac{3}{4}$ feet. Applying rule **10**, Art. **44**, we get

$$D = \frac{1{,}000{,}000 \times (160 + 4.91 + 5.21) \times 518.36 \times 3\frac{3}{4} \times 64{,}800}{188{,}765{,}300}$$
$$= 110{,}996{,}971 \text{ ft.-lb.} \quad \text{Ans.}$$

(19) The area of the piston is $6^2 \times .7854 = 28.27$ square inches and the area of the delivery pipe is $2\frac{1}{2}^2 \times .7854 = 4.91$ square inches. By rule **18**, Art. **52**, we get

$$v = \frac{28.27 \times 85}{4.91} = 489 \text{ ft. per min.} \quad \text{Ans.}$$

(20) Reducing the cubic feet of water to be delivered to pounds, we have $62.5 \times 62.5 = 3{,}906.25$ pounds. Applying rule **7**, Art. **18**, we have

$$P = \frac{10{,}043 \times 35}{3{,}906.25} = 90 \text{ lb., nearly.} \quad \text{Ans.}$$

(21) The velocity of discharge of a flywheel pump is variable throughout the stroke; thus shocks are produced that make it necessary to use a heavier water end than would be used for a direct-acting pump, where the velocity of discharge is practically constant. See Art. **88.**

(22) Reducing the volume of water discharged to pounds, we have $180 \times 62.5 = 11{,}250$ pounds. By rule **5**, Art. **16**, we get

$$L = \frac{23{,}100 \times 25}{11{,}250} = 51.3 \text{ ft.} \quad \text{Ans.}$$

(23) Reducing the water discharged to cubic feet per minute, we have $\frac{66000}{60} = 1{,}100$ cubic feet. Applying rule **17**, Art. **51**, we get for the suction pipe

$$A = \frac{144 \times 1{,}100}{200} = 792 \text{ sq. in.,}$$

and for the delivery pipe

$$A = \frac{144 \times 1{,}100}{500} = 316.8 \text{ sq. in.} \quad \text{Ans.}$$

(24) By rule **8**, Art. **19**, we get

$$W = \frac{10{,}043 \times 75}{150} = 5{,}021.5 \text{ lb. per min.,}$$

or $$\frac{5{,}021.5}{8.34} = 602 \text{ gal. per min.} \quad \text{Ans.}$$

(25) Reducing the volume of water to pounds, we have $128{,}000 \times 62.5 = 8{,}000{,}000$ pounds. Applying rule **15**, Art. **36**, we have

$$D = \frac{1{,}000 \times 8{,}000{,}000 \times 85}{7{,}280} = 93{,}406{,}593 \text{ ft.-lb.} \quad \text{Ans.}$$

(26) By rule **11**, Art. **24**, we get

$$D_g = 3.26 \times 8^2 = 208.64 \text{ gal. per min.} \quad \text{Ans.}$$

(27) The principal difference is in the relative sizes of the steam and water cylinders, the steam cylinder being proportionally much larger for the general-service pumps than for the light-service pumps. See Art. **67**.

(28) The distinguishing feature is the four single-acting plungers working in the ends of the water cylinders. See Art. **70**.

(29) By rule **12**, Art. **26**, we have

$$L = \tfrac{96}{48} = 2 \text{ ft.} \quad \text{Ans.}$$

(30) Outside-packed plungers; strong circular valves independent of one another, but bolted to the working

chamber, to the suction and delivery pipes, and to one another. All parts are made so that they can be easily renewed and sometimes the whole water end is made of some acid-resisting bronze or is made of iron or steel and lined with some acid-resisting material. See Art. **71.**

(31) The valves are frequently made in the form of large leather-faced door or flap valves, giving the full area of the pipe. See Art. **79.**

(32) Many various sizes of pumps can be placed about the mines and driven from an economical generating unit at the surface. See Art. **82.**

(33) Dry vacuum pumps are those that handle air only, while wet vacuum pumps handle both air and water. See Art. **86.**

(34) (*a*) The degree of expansion usually obtained is a little more than the ratio of the high-pressure cylinder to the low-pressure cylinder. See Art. **87.**

(*b*) This ratio is sometimes increased by making the reciprocating parts heavy and running the pump at some fixed minimum speed such that the inertia of the parts will complete the stroke when the steam is cut off in the high-pressure cylinder before the end of the stroke. The degree of expansion may also be increased by the use of a high-duty attachment. See Art. **87.**

(35) The high duty is mainly due to the degree of expansion that can be obtained, and also to the ease with which all the refinements necessary for high duty can be applied. See Art. **89.**

ELEVATORS.

(PART 1.)

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(1) They are classified as hand-power elevators, belt elevators, steam elevators, electric elevators, and hydraulic elevators. See Art. **3.**

(2) An elevator in which the upright posts of the car are placed on diametrically opposite corners. See Art. **4.**

(3) One in which the transmitting devices include a drum and rope. See Art. **5.**

(4) By guiding the rope on the drum by means of a sheave that is caused to follow the motion of the rope back and forth across the drum. See Art. **6.**

(5) (*a*) Making the counterweight heavier than the full weight of the car. See Art. **11.**

(*b*) Hydraulic elevators. See Art. **10.**

(*c*) Because the power can only be applied on the up trip. See Art. **10.**

(6) If the elevator is overbalanced by an amount equal to the average load, no power except that necessary to start the machinery and overcome frictional resistances will be required when lifting the average load, thus enabling a smaller motor to be used. See Art. **11.**

(7) By using a chain attached to the bottom of the car and extending either to the bottom or to the middle of the shaft way, where it is fastened. In the former case the

chain must have the same weight per unit length as the rope to be balanced; in the latter case it must be twice as heavy per unit of length. See Art. **13.**

(8) There is no means of telling the exact position of the controlling device, hence it cannot be applied to motors requiring delicate adjustment. Also, the sliding of the rope through the hand of the operator is inconvenient and may be dangerous. See Art. **17.**

(9) Motor safeties and car safeties. See Art. **26.**

(10) By a shaft actuated through a rope sheave and an endless rope or by a crank driving a windlass. See Art. **29.**

(11) They are generally overbalanced. See Art. **33.**

(12) To avoid undue stress being thrown on the machinery. See Art. **39.**

(13) (*a*) To make them more pliable and thus more durable. See Art. **44.**

(*b*) When the wires commence cracking. See Art. **45.**

(14) Equal parts of linseed oil and Spanish brown or lampblack. Seven parts of linseed oil and three parts of tar oil. Cylinder oil, graphite, tallow, and vegetable tar also make a good preparation. See Art. **46.**

(15) The rope should encircle the drum several times when the elevator is in its lowest position. See Art. **50.**

(16) Because the elevator will be given a jerky motion and the car may then drop sufficiently far in some cases to break the rope. See Art. **51.**

(17) An elevator driven directly by belts from line shafting. See Art. **52.**

(18) Overbalancing spur-geared machines greatly increases the jerkiness of motion, while it has little influence that way on worm-geared ones. See Art. **54.**

(19) By clamping knobs or buttons to the shipper rope in such positions that the car will strike them and cause the belt to be shifted automatically when it reaches the limits of its travel. See Art. **58.**

(20) The most common form of motor limit stop consists of a gear-wheel having a thread cut in its hub and working loosely on a thread cut on an extension of the drum shaft or on a shaft positively driven from the drum shaft. This gear meshes with another of wide face attached to the shipper sheave, and as it is prevented from turning by the wide-faced gear, it travels back and forth on its shaft, its position depending on the position of the car. Should the car overrun its limit of travel in either direction, jaws on the hub of the loose gear engage with jaws fastened to the threaded shaft and thus the loose wheel is rotated. This causes the wide-faced gear to revolve and turn the shipper sheave, which reverses the motion of the elevator. See Art. **59.**

(21) Some form of slack-cable safety is provided that is operated by the slack cable and reverses the direction of motion of the drum. See Art. **60.**

(22) By using two worms on the same shaft, one being right-handed and the other left-handed. The two worms mesh with two worm-gears that are in mesh with each other. See Art. **62.**

(23) 60 feet per minute. See Art. **74.**

(24) Castor oil or a mixture of 2 parts of castor oil and 1 part of the best cylinder oil. See Art. **71.**

(25) The limit stops should be frequently tested; the brake should be adjusted whenever the car settles at the landings; the belts should not be allowed to become slack and they should not be subjected to the influence of steam, water, or oil. All bearings should be kept well lubricated, particularly the step bearing, and the worm-gearing oil bath should be occasionally renewed. See Arts. **66** to **72.**

(26) The principle of the reversing mechanism is that by means of a reversing valve the valves of the engine can be changed from direct to indirect valves. See Art. **80.**

(27) It consists of a rod extending across the under side of the winding drum and so arranged that the loose cable striking it will cause a spring or weight to be released, which will cause the steam to be shut off. See Art. **94.**

ELEVATORS.

(PART 2.)

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(1) (*a*) Continuous-current constant-potential shunt-wound single-speed motors, alternating-current motors, polyphase-synchronous motors, and induction motors. See Art. **5.**

(*b*) For belt-shifting elevators, the continuous-current constant-potential shunt-wound single-speed motors are used. If the motor runs continuously, any kind of alternating-current motor may be used, but if the motor is to be started and stopped frequently, polyphase-synchronous motors or induction motors are used. See Art. **5.**

(2) To prevent a damaging rush of current in starting the motor. See Art. **6.**

(3) The contact bar of the rheostat shown in Fig. 1 of the text is attached to a rack that is driven by a two-toothed pinion, the pinion being on a shaft that is, in turn, driven from the main shaft of the motor. When the motor is started, the rack is drawn into contact with the pinion by means of an electromagnet that is energized by a coil in shunt with the motor circuit, and as the contact bar rises, it gradually cuts out the resistance. As soon as the current is broken, the contact arm drops back and the rack springs out of gear. See Art. **7.**

(4) By connecting across the shunt a series of incandes-
›t lamps having a combined voltage of from 6 to 8 times
of the line current. See Art. **11.**

(5) (*a*) A rheostat in which a solenoid is used to operate the arm that cuts out the resistance. See Art. **13.**

(*b*) It enables the rheostat to be mounted separate from the switch and the switch alone to be operated by the hand rope. See Art. **13.**

(6) It must have a strong torque and it must get up speed rapidly, though gradually. See Art. **17.**

(7) Two-phase or three-phase induction motors. See Art. **17.**

(8) Overbalanced. See Art. **19.**

(9) By mechanical, electrical-mechanical, or wholly electrical attachments. See Art. **21.**

(10) (*a*) The controller consists of a double-throw switch attached to the hub of the shipper sheave and a solenoid rheostat placed near the machine. A casting forming one part of the switch is bolted to the frame of the machine and carries four sets of clips to which the line, field, armature, solenoid, and electric-brake connections are made. By rotating the shipper sheave, the switch blades attached to it may be brought into contact with either of the two sets of clips, thus reversing the motor. See Art. **27.**

(*b*) It gives the rheostat arm time to fall back into its starting position before the current in the armature can be reversed, and it also helps to reduce sparking and flashing at the clips. See Art. **27.**

(11) By means of a dashpot. See Art. **28.**

(12) When the shipper sheave is rotated, the brake magnet is energized and slowly releases the brake. The solenoid is also energized and cuts out the resistance from the armature circuit at such a rate that when the motor is up to speed, the resistance is entirely cut out. When the circuits are broken, the brake is applied and the resistance arm drops back to its original position. See Art. **30.**

(13) The principle of the dynamic brake is that the motor is made to act as a dynamo by means of a variable

resistance so arranged that the armature is short-circuited through it immediately after the line circuit is broken. This has the effect of slowing the motor down quickly but gradually. As the motor slows down, the resistance is gradually cut out, thus making the stop still more gradual. See Art. **31.**

(14) (*a*) In order to make the motor act as a dynamo or brake. See Art. **32.**

(*b*) The field in this case is kept constantly excited, and in order to use less current a resistance is inserted in the fields that are short-circuited when the elevator is started, thus giving the full torque available. When the elevator is stopped, the resistance is cut in, leaving the field current strong enough to get a dynamic-brake effect. See Art. **32.**

(15) (*a*) Both steps are on the same end of the shaft. See Art. **40.**

(*b*) It is easily accessible for inspection or adjustment. See Art. **40.**

(16) The usual traveling-nut, limit-stop, and clutch-operating slack-cable safety, and also a limit switch that brakes the current through the armature and brake solenoid at the limits of the car travel. See Art. **43.**

(17) (*a*) By dividing the pressure between the end surface of the shaft and the ring-shaped surface of a bushing placed around the shaft. See Art. **53.**

(*b*) By means of two small equalizing levers, which distribute the pressure equally over both surfaces. See Art. **53.**

(18) To automatically apply the brake should the current be interrupted in the system. See Art. **59.**

(19) (*a*) The brake is so arranged that it will be set in action by the limit stop much quicker and more effectively than by the ordinary device. See Art. **58.**

(*b*) The tripping device is given considerable lost motion, or backlash, which allows the motor to be stopped without danger of reversing it. See Art. **60.**

(20) To break the main current and thus release the safety brake when the current falls below the normal or when the current becomes excessive. See Arts. **61** and **62.**

(21) The potential switch has three blades with three corresponding double clips, of which the first two are connected to the line wires and the third to a wire leading to the starting resistance. The first two blades are connected to the motor circuit and one of them is also connected to the third blade. An electromagnet placed in shunt across the line and in series with the safety-brake magnet holds the first two blades in contact with their corresponding clips. A spring counteracts the magnet and causes the first two blades to leave their clips and the third blade to engage its clip when the current in the magnet windings falls below the normal. See Art. **61.**

(22) (*a*) In the magnet-control system of operating electric elevators, the starting, stopping, and reversing of the motor and the cutting out of the starting resistance are accomplished by a series of electromagnetic switches that are controlled by a car operating switch on the car. The switches are usually in the form of solenoids or electromagnets that operate whenever current is made to flow through them by means of the car-operating switch. See Arts. **68** and **69.**

(*b*) It avoids the necessity of using the sliding arm and numerous contact plates that are necessary with a rheostat and that always give more or less trouble due to burning and cutting, especially with heavy currents. See Art. **69.**

(23) Give a description similar to that contained in Art. **81.** The action is the same as there described, except that the main switches operate so as to make the current flow through the armature in the reverse direction.

(24) (*a*) The main difference lies in the construction of the switches, the principle of operation being practically the same. Each switch consists of a solenoid arranged so as to draw up a core or plunger to which contact disks are

attached and which make the required connections by being brought into contact with fixed fingers mounted on the switchboard. See Art. **85.**

(*b*) The explanation required is similar to that contained in Art. **88,** except that the operating switch is supposed to be on the down position and, consequently, the direction-controlling switches operate so as to reverse the motor.

(25) (*a*) A description similar to that contained in Arts. **96, 97, 98,** and **99** is required. This can be made considerably shorter than that given in the text, but the path of the operating current and the main current should be described.

(*b*) See Art. **99.**

(26) See Art. **102.**

(27) See Art. **110.**

ELEVATORS.

(PART 3.)

---

(1) Hydraulic elevators are safe, reliable, smooth-acting, and are under perfect control. The wearing parts are few and are easily and cheaply replaced. On the other hand, they require considerable space and usually require the installation of steam pumps, reservoirs, etc., which makes them expensive. See Art. **1.**

(2) (*a*) An elevator in which the car is placed directly on top of the piston or plunger. See Art. **3.**

(*b*) For freight and passenger service for short lifts. See Art. **2.**

(3) Because the power acts only on the up stroke of the elevator. See Art. **6.**

(4) The car would be jerked upwards against the overhead work. See Art. **5.**

(5) As a power control it shuts off the power at the will of the operator, and as a brake it shuts off the water gradually by throttling. See Art. **7.**

(6) By putting in the discharge pipe a throttle valve controlled by the pressure corresponding to the velocity of the exhaust. See Art. **10.**

(7) The cylinder can be made much shorter by introducing multiplying sheaves, and thus the water used per stroke is greatly reduced. See Art. **11.**

(8) Because the car will not tend to teeter up and down when the power is suddenly cut off if the counterweights are arranged in this manner. See Art. **15.**

(9) (*a*) To make the effective pressure on the piston the same at all points of the stroke. See Art. **16.**

(*b*) When the piston is at the top of the cylinder, the weight of the water above it is practically nothing, while the column of water below it exerts a suction corresponding to the height of the column, as long as the column is not higher than 34 feet. As the piston moves down, the weight of water above it increases, while the suction below it decreases by a corresponding amount. Thus the pressure remains constant for all positions of the piston. See Art. **16.**

(10) To avoid the water ram that would occur if the controlling valve was suddenly closed when the piston was descending. See Art. **18.**

(11) (*a*) To control the opening and closing of the main controlling valve. See Art. **19.**

(*b*) Because in high-speed hydraulic elevators the controlling valve cannot be operated directly without danger of producing violent shocks in starting or stopping. See Art. **19.**

(12) The throttle, if properly adjusted, deadens the noise occasioned by the circulating water and serves as a brake in descending. It also prevents the water from rapidly flowing out of the circulating pipe should the supply pipe break. See Art. **23.**

(13) (*a*) An elevator that can be connected either to a high-pressure or a low-pressure tank at the will of the operator. See Art. **25.**

(*b*) In office buildings where it is only occasionally necessary to lift heavy loads. See Art. **25.**

(14) Because the greater the ratio, the shorter the cylinder and hence the less becomes the head of water to be

counterbalanced, thus allowing the non-circulating system to be used. See Art. **26.**

(15) They occupy less valuable floor space and are more accessible than the vertical type. See Art. **28.**

(16) The terms apply simply to the condition of the stress in the piston rod, that is, to whether the rod is in tension or compression when the car is going up. See Arts. **29** and **30.**

(17) Because the whipping of the ropes is very much reduced and thus teetering of the car is prevented to a great extent. See Art. **30.**

(18) By having the tank partly filled with air, which expands as the water is withdrawn. See Art. **39.**

(19) (*a*) By leakage or by absorption in the water. See Art. **39.**

(*b*) By a vent in the suction pipe or by a separate air pump. See Art. **39.**

(20) The Ford regulating valve consists of a spring-actuated steam valve that is operated by a small water piston working in a cylinder that is connected to the pressure tank by a small pipe. As the pressure in the tank rises and falls the water piston rises and falls also, thus causing the steam valve to open or close. See Art. **43.**

(21) The spring-actuated steam valve is replaced by a small water piston valve that controls, by its movement, the amount of water allowed to enter or leave an auxiliary cylinder, to the piston of which is connected a lever operating the switch and rheostat. By this means a comparatively large movement is obtained. See Art. **44.**

(22) To allow the pump to run continuously. See Art. **47.**

(23) By introducing into the tank a layer of heavy oil about 4 inches thick. See Art. **52.**

(24) By opening the vent in the suction pipe when the tank is about half full or by filling the tank two-thirds full

and then pumping up the required pressure by the auxiliary air pump, if one is attached. See Art. **51.**

(25) Run the car to the top and set the controlling valve for going down. While the car and valve are in this position, open the air cock and allow the air to escape. See Art. **52.**

(26) By a groaning in the cylinder or by the car settling at the landings. See Art. **54.**

(27) Connect the exhaust-steam drips from the pump with the discharge tank, thus allowing the cylinder oil to be pumped with the circulating water, by which means all the internal parts of the plant are lubricated. See Art. **57.**

(28) When the car is down, open the air cock and drain-pipe valve and then throw the valve for going up. This will drain the cylinder. To drain the circulating pipe, throw the valve for going down. See Art. **60.**

(29) Run the car to the bottom and close the stop-valve in the supply pipe. Open the air cock at the head of the cylinder and drain the water in the cylinder down to the top of the piston. Remove the cylinder head, and if the piston is not near enough to the top attach a small tackle to the main cables and draw it up within reach. Now, remove the piston follower and renew the packing. After replacing the piston follower, let down the piston to its proper position and replace the cylinder head. Place the operating valve on the center, open the supply-pipe valve, and as soon as the air has escaped close the air cock and the elevator is ready to run. See Art. **67.**

(30) The first and last ring of packing should be of pure rubber cut about 1 inch longer than the circumference of the cylinder. The remaining rings should be of fibrous packing. See Art. **69.**

(31) It should be soaked in boiling tallow for several hours. See Art. **72.**

ELEVATORS.

(PART 4.)

---

(1) The breaking of the cable or cables, the temporary sticking of the car, allowing the cable to become slack, or excessive speed of the car. See Art. **1.**

(2) (*a*) For slow-speed elevators. See Art. **3.**

(*b*) By a wedge that acts between the guides and guide shoes. See Art. **3.**

(3) In order to operate the safety should any one of the cables break, stretch, or become slack. See Art. **5.**

(4) (*a*) Excessive speed of the car. See Art. **6.**

(*b*) By means of a centrifugal governor driven by a rope attached to the car, the safety devices are brought into action when the speed exceeds a certain limit. See Art. **6.**

(5) The governor is operated by a rope that is attached to the finger shaft of the safety device. When the speed becomes excessive, the governor balls fly out and operate a clutch consisting of two eccentrics that grip the rope and hold it firmly. Consequently, as the car descends the tension on the rope becomes great enough to rotate the finger shaft and thus operate the safety device. See Art. **7.**

(6) To insure a gradual fall of the car, thus giving the safety time to act, should the hoisting rope break. See Art. **12.**

(7) Because they might cause the safety wedges to stick and be thrown into action. See Art. **16.**

(8) All slack in the hoisting cables should be taken up. See Art. **17.**

(9) Remove the limit-stop button on the shipper rope and raise the car enough to unlock the wedges. If this cannot be done, the car may be lifted by a tackle. See Art. **17.**

(10) The air-cushion safety consists of an extension of the hoistway below the lowest landing in the form of a pit. The cross-section of the pit is such that the car is gradually brought to rest by the escape of the air contained in the pit through the space between the sides of the car and the sides of the pit. See Art. **18.**

(11) (*a*) The depth of the pit should be about one-fifth the whole lift. See Art. **19.**

(*b*) By making the lower part of the hoistway air-tight. See Art. **19.**

(12) (*a*) In case of fire, the shaft would act as a chimney and carry the fire from floor to floor. The closed shaft is always dark, and if windows are placed in the walls the danger from fire is increased. See Art. **20.**

(*b*) About 5 feet, or high enough to prevent people bending over the enclosure to look for the car. See Art. **20.**

(13) Elevator doors should be sliding doors or gates that operate freely. They should be so locked that they can only be opened from the inside of the shaft. Self-locking doors are preferable. See Art. **21.**

(14) By means of a car-locking device that prevents the operation of the starting or operating device in the car while the door is open. See Art. **25.**

(15) By means of mechanically operated indicators that indicate the position of the car and whether it is going up or down. See Art. **29.**

(16) For that class of service where the lift is short and where great numbers of people are to be carried. See Art. **33.**

STEAM HEATING.

(1) In the one-pipe system, but one line of pipe is used to connect the boiler and radiators. This necessitates returning the water of condensation to the boiler through the steam main. See Art. **17.**

(2) The manner of returning the water of condensation to the boiler. See Art. **16.**

(3) The circulation is uncertain, owing to the formation of slugs of water in the pipes; the steam is likely to be wet, as it is always in contact with the returning water; water hammer and sizzling noises are very liable to occur; in the case of large systems, the return of the water of condensation through the steam pipes greatly interferes with the flow of steam to the radiators. See Arts. **21** and **23.**

(4) About $\frac{1}{2}$ inch in 10 feet. See Art. **26.**

(5) By using vertical offsets or relays. See Art. **28.**

(6) (*a*) No. See Art. **30.**

(*b*) The expansion of the riser will either bend the main or raise the radiators connected to it. The weight of the riser will also tend to bend the main. See Art. **30.**

(7) If the steam valve is left slightly open, the steam will be condensed as fast as it enters the radiator; and as the opening is so small, little or no water will escape. See Art. **22.**

(8) If there is a slight difference in the pressure at the various radiators, the steam will flow backwards through the

return pipes and interfere with the drainage or cause water hammer. See Art. **36.**

(9) Using rule 1, Art. **41,** the diameter is found to be

$$\sqrt{\frac{5000}{100} \div .7854} = 7.97 \text{ in., or 8 in. in practice. Ans.}$$

(10) About $1\frac{1}{2}$ inches per hundred feet. See Art. **43.**

(11) Using rule 2, Art. **42,** we find the surface to be

$$6^2 \times .7854 \times 100 = 2{,}827.4 \text{ sq. ft. Ans.}$$

(12) By a hydrostatic test to detect any defective fittings or split pipes, and by a steam test to see if expansion has been properly provided for and that the system is in working order. See Art. **53.**

(13) (*a*) By increasing the emitting surface, the heat is given off more rapidly and with but little decrease in temperature of the heat-transmitting surfaces. See Art. **75.**

(*b*) No; the plain surfaces clear themselves more readily than the extended surfaces and are, therefore, more effective. See Art. **75.**

(14) The air has free access to the tubes, and as it does not pass over but one row of tubes, each tube will operate upon air of equally low temperature, thus making the rate of emission of heat a maximum. See Art. **78.**

(15) The interior of the radiator is well supplied with air and the flues impart a high velocity to the warmed air, which greatly increases the efficiency of the flue heating surfaces. See Art. **80.**

(16) (*a*) The top tubes will be warmer than the bottom ones and thus expand more, which will cause the pipes to bulge and the joints to leak. See Art. **83.**

(*b*) A miter coil should be used. See Art. **82.**

(17) The Nason tube is simply a tube capped at one end and divided into two passages by a sheet-iron plate that extends nearly to the end of the tube. The lower end of

the tube is screwed directly into the radiator base. See Art. **86.**

(18) By enclosing the base so that the fresh air, as it enters, is compelled to pass between the hot tubes before escaping into the room. See Art. **91.**

(19) Because the steam pressure may back up the water of condensation into the radiator through the returns and flood the building. See Art. **99.**

(20) If a single large radiator were used, it would probably be difficult to regulate the temperature during mild weather. By using two radiators, one being larger than the other, the small one may be used during mild weather, the large one during moderate cold weather, and both during severe weather. See Art. **96.**

(21) The amount of glass surface is $3\frac{1}{2} \times 6 \times 3 = 63$ square feet. The exposed wall surface reduced to a glass surface is $\frac{10\ (20 + 30) - 63}{10} = 43.7$ square feet. The total cooling surface is $63 + 43.7 = 106.7$ square feet. By rule **3**, Art. **94**, the number of square feet of radiating surface required is $\frac{70 - 0}{225 - 70} \times 106.7 = 48.2$ square feet, nearly. Adding 30 per cent. for air leakage, we have $48.2 + 48.2 \times .30 = 62.7$ square feet, and now allowing 25 per cent. to allow for exposure to winds, we have $62.7 + 62.7 \times .25 = 78.37$, say 78.4 square feet. Ans. See Arts. **95** and **96.**

(22) The radiator valve leaks. See Art. **99.**

(23) The air valve is probably choked or closed. See Art. **98.**

(24) As far as possible from the steam inlet so that the air vent will not close before all the air has escaped. See Art. **70.**

(25) (*a*) The ordinary air vent allows water as well as air to escape.

[illegible] It may be remedied by placing a float on the air-valve stem so that the water will lift the stem and close the valve when it tries to escape. See Arts. 68 and 69.

[illegible] The intermittent results are produced, as the air contained in the circulating water is liberated and expands when the water is heated and thus tends to counteract the effect of condensation. See Art. 64.

INDEX.

NOTE.—All items in this index refer first to the section (see the Preface) and then to the page of the section. Thus, "Annunciator 40 25" means that annunciator will be found on page 25 of section 40.

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E.